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SEDIMENT TOTAL MAXIMUM DAILY LOAD FOR CROW CREEK, LARAMIE COUNTY, WYOMING

Topical Report RSI-2325

prepared for

Wyoming Department of Environmental Quality
122 West 25th Street
Herschler Building
Cheyenne, Wyoming 82002

March 2014

RESPEC CONSULTING & SERVICES

AYRES ASSOCIATES

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Topical Report RSI-2325

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Total Maximum Daily Load Summary	
Waterbody Name/Description	Crow Creek (from Happy Jack Road downstream to Hereford Reservoir #1)
Assessment Unit I.D.	WYSP101900090107_03
Size of Impaired Waterbody	9 miles (14.5 kilometers)
Size of Watershed (Project Area)	257.5 square miles (666.9 square kilometers)
Size of Watershed (Impairment)	63.3 square miles (163.9 square kilometers)
Location	10-digit Hydrologic Unit Code (HUC): 1019000902
Impaired Designated Use(s)	Aquatic Life Other Than Fish
303(d) Listing Parameter	Sediment
Cycle Most Recently Listed	2010 Wyoming Integrated Report
Total Maximum Daily Load Priority Ranking	2010 (Wyoming Priority Rankings are Total Maximum Daily Load Dates)
Total Maximum Daily Load Criteria Threshold Values	Indicator name: Sediment Threshold Values: In all Wyoming surface waters, substances attributable to or influenced by man that will settle to form sludge, bank or bottom deposits, and floating and suspended solids attributable to or influenced by the activities of man shall not be present in quantities that could result in significant aesthetic degradation; significant degradation of habitat for aquatic life; or adversely affect public water supplies, agricultural or industrial water use, plant life, or wildlife.
Analytical Approach	**HEC-RAS** sediment transport and **HSPF** watershed modeling

Total Maximum Daily Load Component (tons/day)	Flow Zone				
	High	**Moist**	**Midrange**	**Dry**	**Low**
	> 248 cfs	**248–126 cfs**	**126–86 cfs**	**86–47 cfs**	**< 47 cfs**
Load Allocation	21	9	5	2	1
Wasteload Allocation	185	86	42	20	14
Margin of Safety	23	11	5	2	2
Total Maximum Daily Load	229	106	52	24	17

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1.0 INTRODUCTION

Section 303(d) of the Clean Water Act and the U.S. Environmental Protection Agency's (EPA) Water-Quality Planning and Management Regulations (40 CFR Part 130) requires states to develop Total Maximum Daily Loads (TMDLs) for waterbodies that do not meet applicable water-quality standards or guidelines for protecting designated uses under technology-based controls. TMDLs specify the maximum pollutant amount a waterbody can receive and still meet water-quality standards. Based on a calculation of the total allowable load, TMDLs allocate pollutant loads to sources incorporating a margin of safety. TMDL pollutant load reduction goals for significant sources provide a scientific basis for restoring surface water quality and linking, developing, and implementing control actions to attain and maintain water-quality standards and designated uses.

This document clearly identifies the components of a TMDL, supports adequate public participation, and facilitates the EPA review. The TMDL was developed in accordance with Section 303(d) of the federal Clean Water Act and guidance developed by the EPA. This TMDL document addresses the sediment impairment in the Crow Creek Watershed. The impaired waterbody is assigned Classes 2AB and 2C in the Wyoming Water Quality Assessment and Impaired Waters List [Wyoming Department of Environmental Quality, 2010]. The Wyoming Department of Environmental Quality [2007] states that:

> *Class 2AB waters are those known to support game fish populations or spawning and nursery areas at least seasonally and all their perennial tributaries and adjacent wetlands and where a game fishery and drinking water use is otherwise attainable. Class 2AB waters include all permanent and seasonal game fisheries and can be either "cold water" or "warm water" depending on the predominance of cold-water or warm-water species present. All Class 2AB waters are designated as cold-water game fisheries unless they are identified as a warm-water game fishery by a "ww" notation in the "Wyoming Surface Water Classification List." Unless it is shown otherwise, these waters are presumed to have sufficient water quality and quantity to support drinking water supplies and are protected for that use. Class 2AB waters are also protected for nongame fisheries, fish consumption, aquatic life other than fish, recreation, wildlife, industry, agriculture, and scenic value uses.*
>
> *Class 2C waters are those known to support or that have the potential to support only nongame fish populations or spawning and nursery areas at least seasonally (including their perennial tributaries and adjacent wetlands). Class 2C waters include all permanent and seasonal nongame fisheries and are considered "warm water." Uses designated on Class 2C waters include nongame fisheries, fish consumption, aquatic life other than fish, recreation, wildlife, industry, agriculture, and scenic value.*

Because the narrative standards are linked to the designated use that is the most sensitive to sediment (i.e., aquatic life), addressing aquatic life for this TMDL provides protection for any

other designated uses assigned to this waterbody. Water-quality standards for Wyoming surface water also include a regulatory policy concerning antidegradation that states "water uses in existence on or after November 28, 1975, and the level of water quality necessary to protect those uses shall be maintained and protected" [Wyoming Department of Environmental Quality, 2007].

1.1 CLEAN WATER ACT SECTION 303(D) LISTING INFORMATION

In Wyoming [Wyoming Department of Environmental Quality, 2010], one stream segment on Crow Creek downstream from the confluence of North Fork and Middle Fork Crow Creek was listed as nonsupportive of the aquatic life use because the bed material load was high. The segment, WYSP101900090107_03, was defined as Crow Creek from Happy Jack Road downstream to Hereford Reservoir #1. The project area for the TMDL assessment is defined as the Crow Creek Watershed beginning at the confluence of North Fork Crow Creek and Middle Fork Crow Creek approximately 8.5 miles west of Cheyenne, Wyoming, to the Wyoming and Colorado border. The 9-mile-long impaired reach drains approximately 63.3 square miles, not including the upstream area and downstream areas. Figure 1-1 provides a map of the project area and the impaired reach.

The Wyoming Department of Environmental Quality (WDEQ) water-quality standards [Wyoming Department of Environmental Quality, 2007] state that:

> *In all Wyoming surface waters, substances attributable to or influenced by the activities of man that will settle to form sludge, bank, or bottom deposits shall not be present in quantities which could result in significant aesthetic degradation, significant degradation of habitat for aquatic life or adversely affect public water supplies, agricultural or industrial water use, plant life or wildlife.*
>
> *In all Wyoming surface waters, floating and suspended solids attributable to or influenced by the activities of man shall not be present in quantities which could result in significant aesthetic degradation, significant degradation of habitat for aquatic life, or adversely affect public water supplies, agricultural or industrial water use, plant life or wildlife.*

Other applicable water quality standards in this Class 2AB and Class 2C stream segment are summarized in the *Wyoming Water Quality Rules and Regulations* [WDEQ, 2007].

The WDEQ previously completed an assessment [Hargett, 2009] to determine the physical, chemical, and biological water-quality condition of Crow Creek. The assessment also was used to determine whether or not Crow Creek fully supported its designated uses. For the assessment, Crow Creek at Happy Jack Road was selected to represent this best attainable condition. This site was used as a control site to compare biological and physical data from reference urban sites.

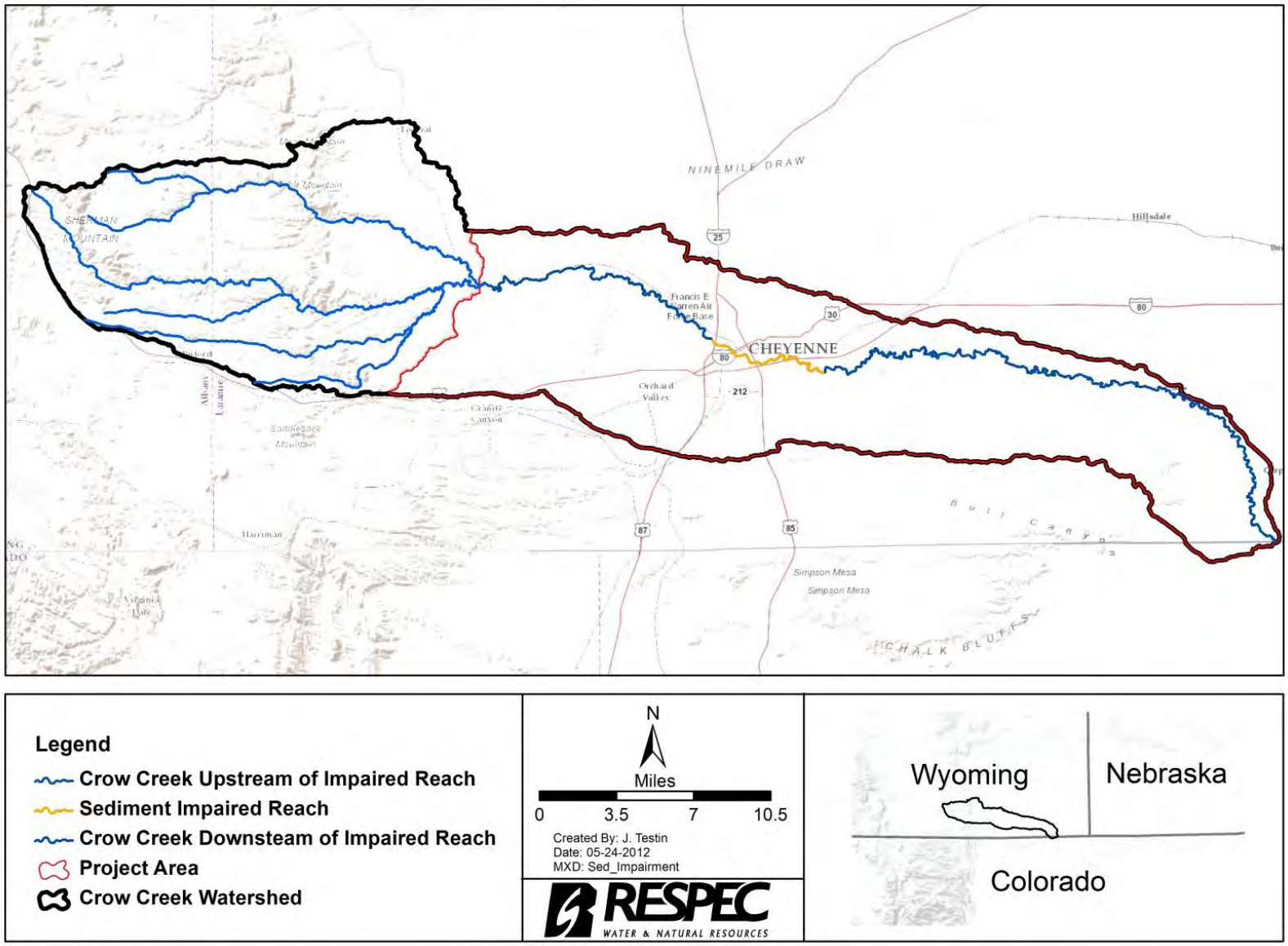

Figure 1–1. Crow Creek Project Area and Sediment-Impaired Reach.

The assessment used the Watershed Assessment of River Stability and Sediment Supply (WARSSS) procedure [Rosgen, 2006] to determine the physical condition of Crow Creek, and the WARSSS River Stability Prediction (RSP) procedure to support quantitative calculations of channel stability and sediment supply, or the amount of sediment being delivered to the stream from external sources. Additionally, many water chemistry and physical water-quality parameters were measured. The assessment determined the biological condition of the stream by using the Wyoming Stream Integrity Index (WSII) and the Wyoming River InVertebrate Prediction and Classification System (WY RIVPACS). The WSII is a regionally calibrated, macroinvertebrate-based, mulitmetric index designed to assess aquatic life use support in Wyoming streams [Hargett and Zumberge, 2006]. WY RIVPACS is "a statewide macroinvertebrate-based predictive model that assesses stream biological condition by comparing macroinvetebrate taxa observed at a site of unknown biological condition with the indigenous macroinvertebrae taxa expected to occur with minimal or no human disturbance [Hargett, 2009]."

The assessment linked the impaired biological condition back to the water-quality pollutant primarily causing the impairment, which was determined to be excess sediment contributions, by using Canonical Correspondence Analysis. The linkage between sediment and the impaired biological condition in Crow Creek, which led to Crow Creek being listed as impaired for sediment, is discussed in more detail in Chapter 2.0. While WSII and WY RIVPACS scores from these locations can be used to determine whether or not the stream is meeting its designated uses, this TMDL uses sediment transport capacity, or the volume of sediment that Crow Creek is able to carry downstream, at the critical reach (Morrie Avenue) to determine the allowable load.

Although the substrate material at Happy Jack Road has similar characteristics to the material within the impaired reach, the substrate material at Deming Drive is more representative of the impaired reach. Therefore, TMDL targets in this report reference a biological condition within a range of biological conditions measured between Happy Jack Road and Deming Drive.

1.2 WATERSHED CHARACTERISTICS

The Crow Creek Watershed (Hydrologic Unit Code [HUC] 10190009) is located in Laramie County in the southeastern part of Wyoming. The headwaters of Crow Creek originate in Albany County. Crow Creek begins at the confluence of North Fork Crow Creek and Middle Fork Crow Creek approximately 8.5 miles west of Cheyenne, Wyoming, and flows east to southeast to its confluence with the South Platte River in Colorado.

The Morrie Avenue Bridge is the point where most major sediment contributions from the urbanized area have been delivered to the stream. Therefore, the reach between Happy Jack Road and the Morrie Avenue Bridge has been identified as the critical reach (i.e., highest level of impairment); for this reason, the TMDL was based on conditions at the Morrie Avenue Bridge

instead of the TMDL endpoint at Hereford Reservoir #1. This shift in the TMDL endpoint leads to a more conservative TMDL that requires a higher reduction of bed material sediment load, which is more protective of the designated use. For the purposes of this document, bed material sediment load is defined as material that is stored in the streambed that becomes mobile during high flow events.

The Crow Creek project area is represented by suburban, urban, industrial, and grazing areas in and around the city of Cheyenne MS4 area. Urban stormwater runoff, water treatment facilities, and industrial facilities are suspected to influence sediment in the project area. Above and below the project area, land use is primarily characterized by dryland farming, irrigated farming, industry, livestock grazing, and small housing developments. Water-quality influences in the project area are grazing, irrigation, small housing developments, industry, and stormwater carry-over [Laramie County Conservation District, 2008].

1.2.1 Land Cover and Land Use

A summary of land cover and land use was completed by using the 2001 National Land Cover Dataset (NLCD). The 2001 NLCD is summarized and was used to represent the project area because the 2006 NLCD was unavailable when this project was initiated. The NLCD is a 21-category, multilayer land cover classification dataset that is derived from Landsat imagery and ancillary data and provides consistent land cover data for all 50 states [Multi-Resolution Land Characteristics Consortium, 2001]. Land uses for the Crow Creek project area are listed in Table 1-1. Approximately 81 percent of the land cover and land use of the Crow Creek project area consists of herbaceous grasslands, and the remaining areas consist of cultivated crops, developed land, and other small land uses, as illustrated in Figure 1-2. Cheyenne is the only large urban area within the watershed with a population of 60,000 and an incorporated area of approximately 45 square miles. The most recent land cover dataset available for the city of Cheyenne (representing the year 2000) was also used for this project.

Table 1-1. Land Use by National Land Cover Dataset Category in the Project Area

NLCD Land-Use Category	Area (mi^2)	Percent of Total
Grassland, Herbaceous	208.5	80.9
Cultivated Crops	12.5	4.9
Developed, Low Intensity	11.5	4.4
Developed, Open Space	9.7	3.8
Developed, Medium Intensity	6.9	2.7
Other	8.4	3.3
Total	**257.5**	**100**

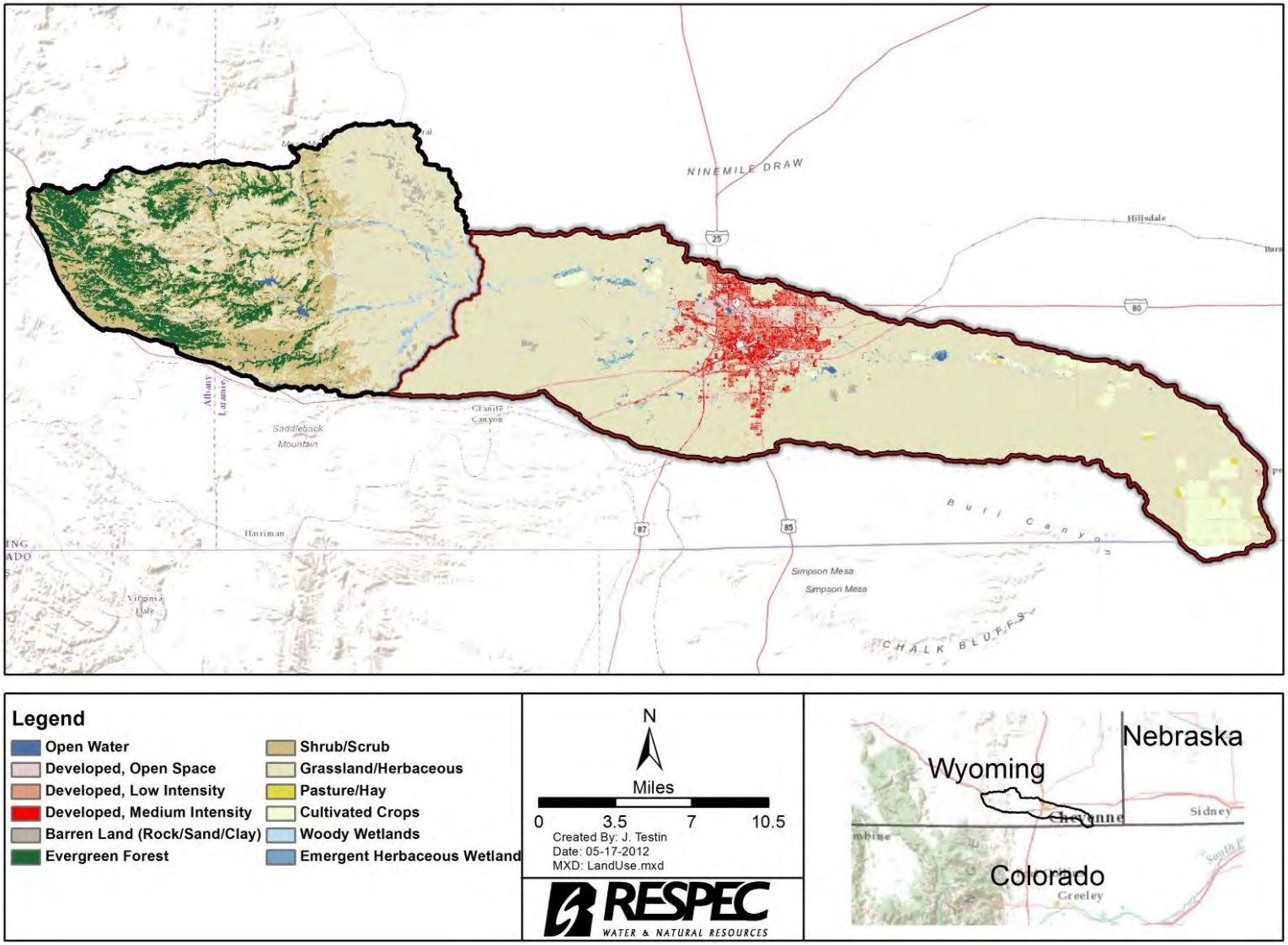

Figure 1–2. Predominant Land Cover and Land Use.

1.2.2 Precipitation

The average annual precipitation obtained from the Natural Resources Conservation Service (NRCS) Geospatial Data Gateway is generally consistent throughout the Crow Creek project area with a typical annual precipitation between 13 and 17 inches per year, as illustrated in Figure 1-3. Maximum monthly precipitation (years 1990 through 2011), which is discussed further in the seasonality section, generally occurs in the spring and early summer months at the Cheyenne airport.

1.2.3 Irrigation

The largest consumptive use of water (approximately 80 to 85 percent) in Wyoming is from agricultural irrigation, and the primary source is surface water. Irrigation waters from surface sources in the watershed are mainly from South Crow Creek via the Gilchrist #4 Diversion (14 miles west of Cheyenne), which has a permitted conveyance of 37.5 cubic feet per second (cfs). A number of smaller irrigation diversions are also in the watershed [Wyoming State Water Plan Platte River Basin Water Atlas, 2010]. Irrigated land in the project area is shown in Figure 1-4.

1.2.4 Geology and Soils

The study area is located within the Denver Basin, which is immediately east of the Laramie Mountains. In general, this area consists almost entirely of Tertiary- and Quaternary-age deposits. These deposits were derived from sediment that eroded off the Laramie Mountains approximately 60 million years ago after the mountains were uplifted as part of the Laramide orogeny. The surficial geology from the Wyoming State Geology Geographic Information System (GIS) data is displayed in Figure 1-5.

The Ogallala Formation (Tmu) deposited in the Upper Miocene lies under approximately 90 percent of the project area and includes the majority of the area that drains to the impaired reach of Crow Creek. These rocks primarily consist of light-colored claystone, sandstone, and gravel conglomerate. Additionally, several volcanic ash deposits can be found within the upper sequences of the Ogallala Formation. The formation was deposited in a complex, alluvial sequence with inherent heterogeneity, although most clasts are derived locally.

Two small areas of the exposed Tertiary White River Formation (Twr) are at the east and the west ends of the project area. The White River Formation is predominantly composed of pale-to-white, tuffaceous claystone and sandstone. Thin, Quaternary alluvial and gravel deposits (Qt) are also present at the easternmost edge of the project area.

1.3 PROJECT-SPECIFIC MONITORING

Because discharge and water-quality data gaps existed throughout the watershed, 2 years of discharge and sediment sampling were completed (2010 and 2011) before developing the TMDL.

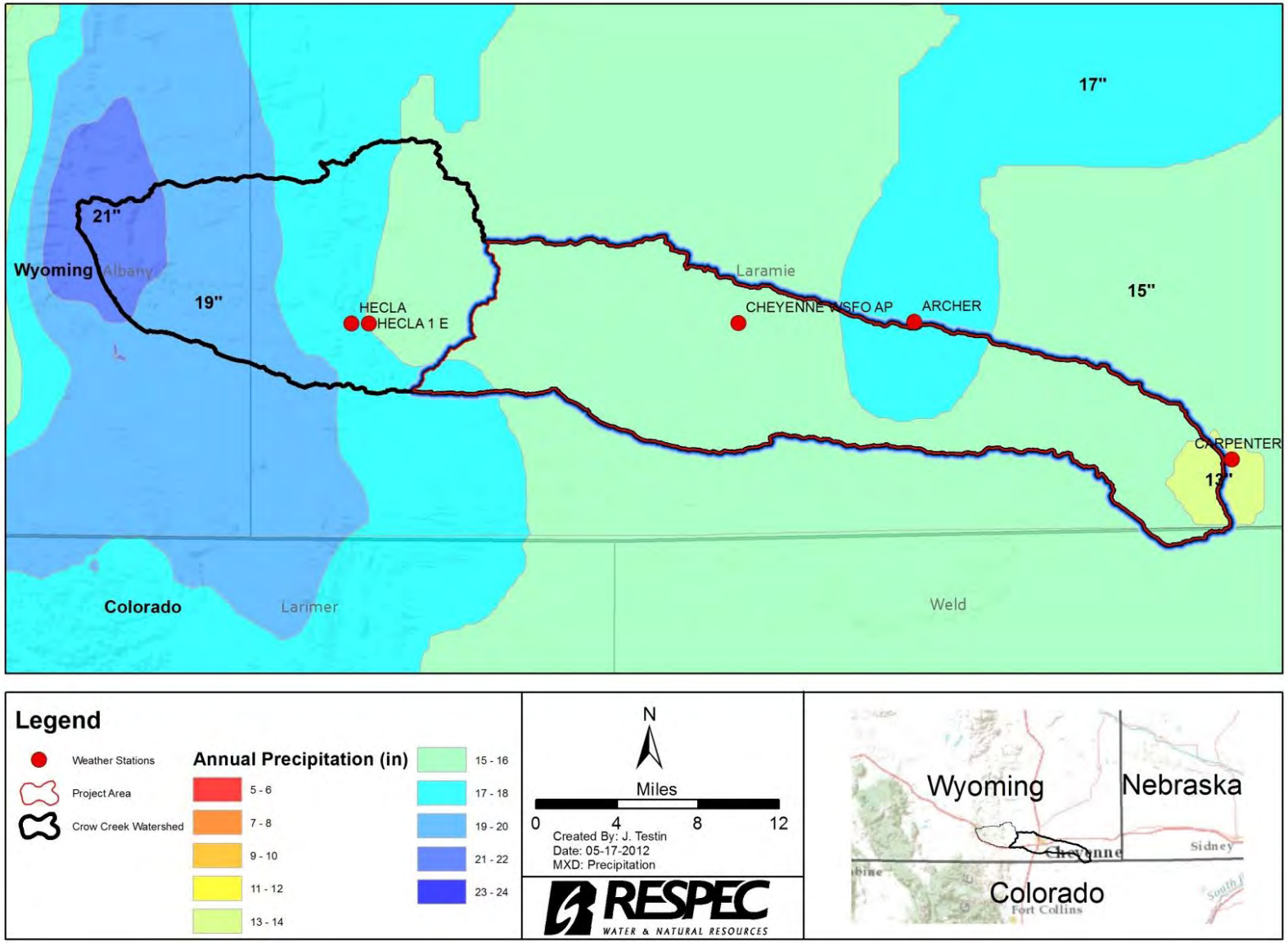

Figure 1–3. Average Annual Precipitation Within the Project Area.

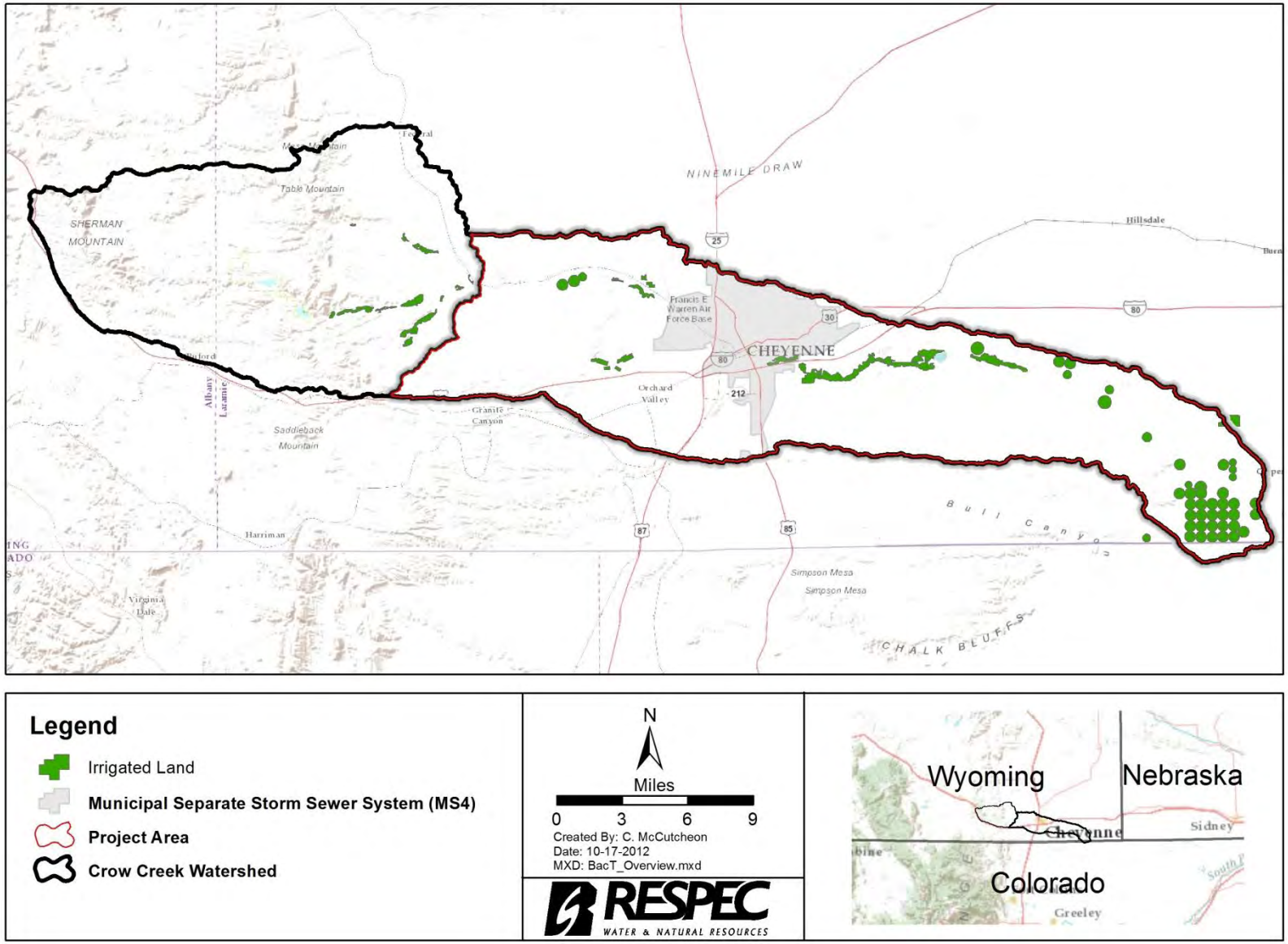

Figure 1–4. Irrigated Land Within the Project Area.

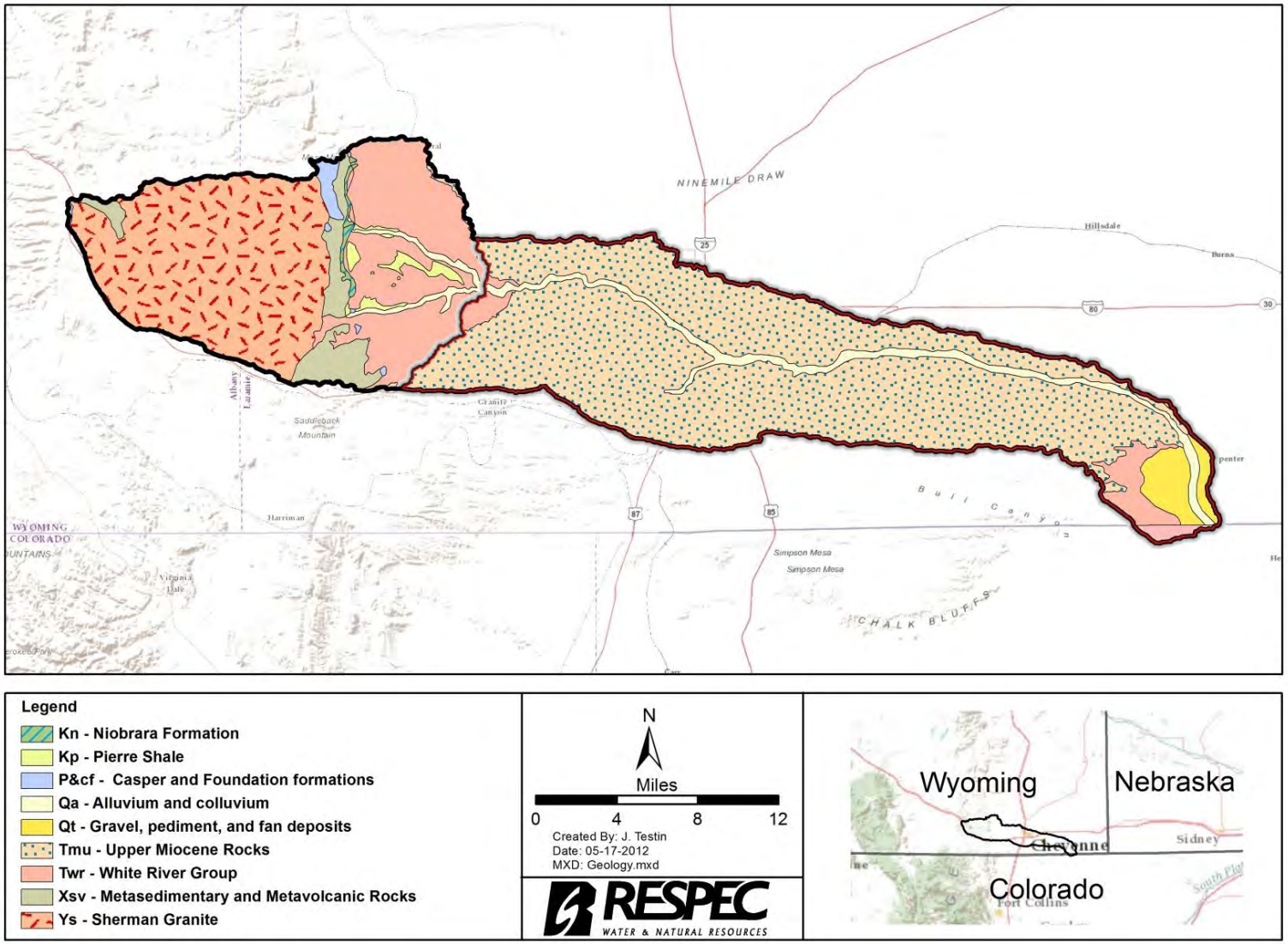

Figure 1–5. Bedrock Geology Distribution in the Crow Creek Watershed.

Sediment sampling included grab samples during both base flow and storm events, storm event sampling using automated water-quality (ISCO) samplers (aliquots and flow-weighted composite samples), bedload sampling, and depth-integrated sediment sampling. Additional samples included traditional quality assurance/quality control (QA/QC) sample sets comprising of 10 percent duplicates and 10 percent field blanks. The following section outlines the monitoring efforts.

1.4 DISCHARGE MONITORING

Sampling sites with site I.D.s are illustrated in Figure 1-6. Staff gages and continuous stage-recording equipment were installed at all sites. ISCO continuous stage equipment was installed at all ISCO sites, which included CRC300, CRC500, CRC600, CRC700, STW200, STW300, and STW500. STW300 did not receive enough flow during storm events, so the automated sampler was relocated to STW400 in June 2010. Pressure transducers were installed at CRC100, CRC800, CRC900, CLC800, and STW800. At the inception of the project, flow was measured often to construct stage-discharge ratings at each site. After adequate discharge ratings were constructed, flow was measured occasionally to check and adjust ratings. When possible, flow was also measured during extreme high and low flow events to extend the range of the rating curve. Manning's equation was used to convert depth to flow for urban drainage sites where concrete culverts were present; stage-discharge ratings were used at all other sites. Continuous flow data are necessary to compute aliquot volumes for event mean concentration (EMC) samples and are a critical component in TMDL calculations.

1.4.1 Sediment Grab Samples and ISCO Automated Sampling

Base grab samples were collected five times per month in conjunction with the Laramie County Conservation District (LCCD) sampling and resulted in 20 grab samples per year at each site. Sediment grab samples were analyzed for total suspended solids (TSS). The initial sampling goal was to collect six storm event samples per year. A storm event was defined as having at least 0.1 inch of rain preceded by at least 72 hours of dry weather. The storm events were sampled using ISCO samplers with 24 individual aliquots that provided a means for measuring the EMCs of each storm. The ISCO samplers were manually triggered during runoff events by using cellular phone modems. Aliquot collections were spaced 20 minutes apart for the first 10 aliquots, and up to an hour apart for the last 14 aliquots. Aliquot collection intervals varied with sampler locations. Storm event samples submitted for analyses included a flow-weighted composite of the 24 ISCO aliquots, a grab sample from the stream, and the aliquot from the ISCO collected at the closest time to the grab sample. The grab sample and the individual ISCO aliquot were analyzed for QA/QC purposes and allowed for comparisons between the ISCO composite, the grab, and the aliquot.

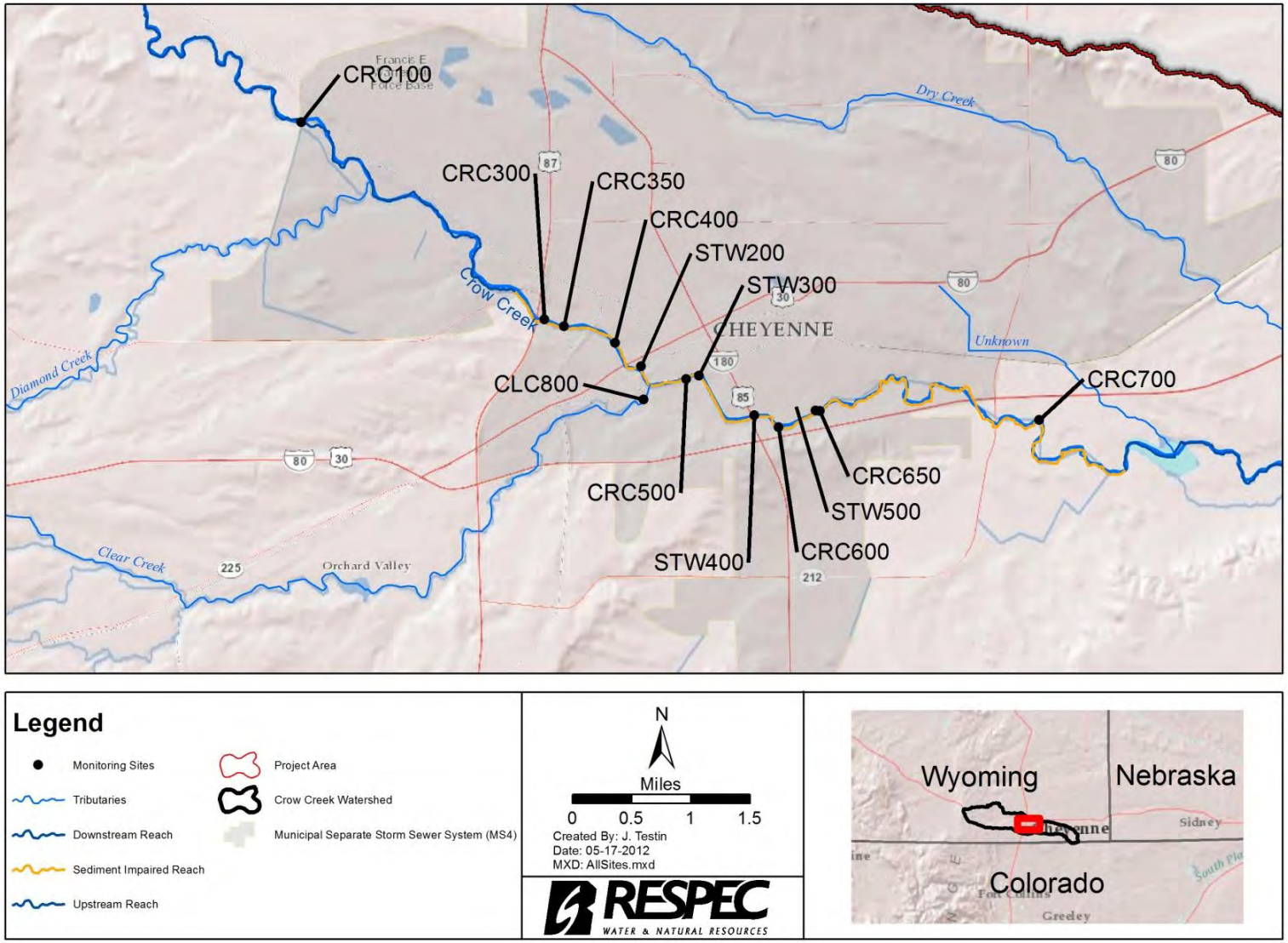

Figure 1–6. Crow Creek Project Area Sites With Sediment Data Including Tributaries and Stormwater Outfalls.

1.4.2 Bedload and Integrated Sediment Sampling

Bedload samples were collected during the six storm events at three instream sites by using hand-held samplers. The purpose of sampling at different stream discharges was to develop a relationship between discharge and bedload at each site. Field crews used an extension handle to sample bedload from a bridge when water was too deep or swift for measurement. Concurrent depth-integrated TSS samples were collected by using the equal-width-increment method. Stage data were collected each time samples were collected.

1.5 SUMMARY OF AVAILABLE FLOW DATA

Figure 1-6 shows all of the sites with flow and/or TSS data throughout the project area. The U.S. Geological Survey (USGS) available flow data are provided in Table 1-2. The USGS collected continuous discharge at CRC100 and CRC300 from March 1994 through September 1996 and at CRC400 from October 1993 through the present. Any flow data collected by the USGS at other sites outside of the listed time periods were instantaneous samples. For this project, continuous discharge was also collected at 13 sites, which are provided in Table 1-3, throughout the project area. The relative flow contribution (percent) throughout the project area is illustrated in Figure 1-7. This relative flow contribution was calculated as the percent of the flow volume at the most downstream site (CRC800) using daily average flow on days when all included sites had flow data available.

Table 1-2. Summary of U.S. Geological Survey Flow Data

Site	Site Description	USGS Site I.D.	Type	Start Date	End Date	Number of Samples
CRC100	Crow Creek near Round Top Road	06755800	Continuous	03/21/1994	09/30/1996	925
			Instantaneous	06/16/1986	09/24/1992	33
CRC300	Crow Creek near F.E. Warren Air Force Base	06755950	Continuous	03/21/1994	09/30/1996	925
			Instantaneous	05/27/1983	08/18/1994	76
CRC400	Crow Creek near Martin Luther King Park	06755960	Continuous	10/01/1993	12/31/2011	6,663
CRC705	Crow Creek near Cheyenne	06756000	Instantaneous	11/02/1973	09/24/1992	98
CRC755	Crow Creek near Archer	06756060	Instantaneous	11/01/1990	02/25/2010	79

1.6 SUMMARY OF AVAILABLE WATER-QUALITY DATA

The project team collected TSS, bedload, bed material, and floodplain samples in 2010 and 2011. The water-quality data for these samples are described in the following text.

Table 1-3. Summary of Total Maximum Daily Load Project-Specific Continuous Flow Data

Site	Site Description	Start Date	End Date	Stage-Discharge Relationships/ Manning's Equations
CRC100	Crow Creek near Round Top Road	05/20/2010	08/24/2011	$h \le 5.37;\ Q = 15.962(h-3.29)^{2.38}$ $h > 5.37;\ Q = 0.007(h-0.1)^{5.7}$
CRC300	Crow Creek near F.E. Warren Air Force Base	07/08/2010	09/26/2011	$Q = 14.558(h-12.953)^{2.143}$
STW200	Capitol Basin near Ames Ave	07/08/2010	07/24/2011	$Q = (1.49/0.014)(R^{2/3})(0.007^{1/2})A$ [(a)]
CLC800	Clear Creek at Confluence	05/20/2010	06/10/2011	$Q = 0.048(h-3.684)^{6.851}$
CRC500	Crow Creek West of Ames Ave	07/08/2010	09/26/2011	$Q = 5.013(h-2.569)^{2.871}$
STW400	Union Pacific near I-80	08/01/2010	09/26/2011	$Q = (1.49/0.014)(R^{2/3})(0.0336^{1/2})A$ [(a)]
CRC600	Crow Creek near 1st Street	07/04/2010	08/23/2011	$Q = 8.79(h-12.504)^{2.296}$
STW500	Morrie Ave near E 1st Street	07/08/2010	09/01/2011	Box Culvert (used depth, velocity, and culvert geometry)
CRC700	Crow Creek upstream of Waste Water Treatment Plant (WWTP)	07/4/2010	09/26/2011	$Q = 4.236(h-2.422)^{2.346}$
STW800	E Lincolnway Basin near South Industrial Road	05/20/2010	08/24/2011	$Q = 31.183(h-3.987)^{2.51}$
DRC800	Dry Creek near Confluence	07/08/2010	09/26/2011	$Q = (1.49/0.012)(R^{2/3})(0.0016^{1/2})A$ [(a)] width = 12 ft
CRC800	Crow Creek near Missile Road	05/20/2010	09/27/2011	$h \le 12.9;\ Q = 43.07(h-11.78)^{1.428}$ $h > 12.9;\ Q = 0.001(h-7)^{5.875}$
CRC900	Crow Creek South of Intersection of Road 144/Road 207	05/20/2010	09/27/2011	$Q = 32.52(h-13.9)^{2.257}$

(a) Manning's equation was used instead of a stage-discharge equation
Q = flow, cfs
h = stage, feet
A = area, square feet
R = hydraulic radius, feet

1.6.1 Total Suspended Solids Data

Sampled TSS loads were used to develop bed material sediment supply predictions for the TMDL, and the **HSPF** model was calibrated to TSS and later converted to bed material load by using regression equations developed from the sample data (discussed further in Chapter 3.0) to relate TSS and bed sediment loads. The TSS data were collected specifically for this project (grabs, aliquots, and flow-weighted composites) from spring 2010 to fall 2011. The samples were collected during event flows and base flows at mainstem, tributary, and stormwater outlet sites on Crow Creek. The site descriptions, date ranges, and sample types for TSS data used in this TMDL analysis are provided in Table 1-4. Urban stormwater monitoring

data collected within the storm drainage network in the urban area were used to evaluate sediment loads from the Municipal Separate Storm Sewer Systems (MS4s). Stormwater monitoring sites are provided in Table 1-4 and are labeled with an "STW" in the Site I.D. Quality assurance information for the data collected specifically for this project is included in Appendix A.

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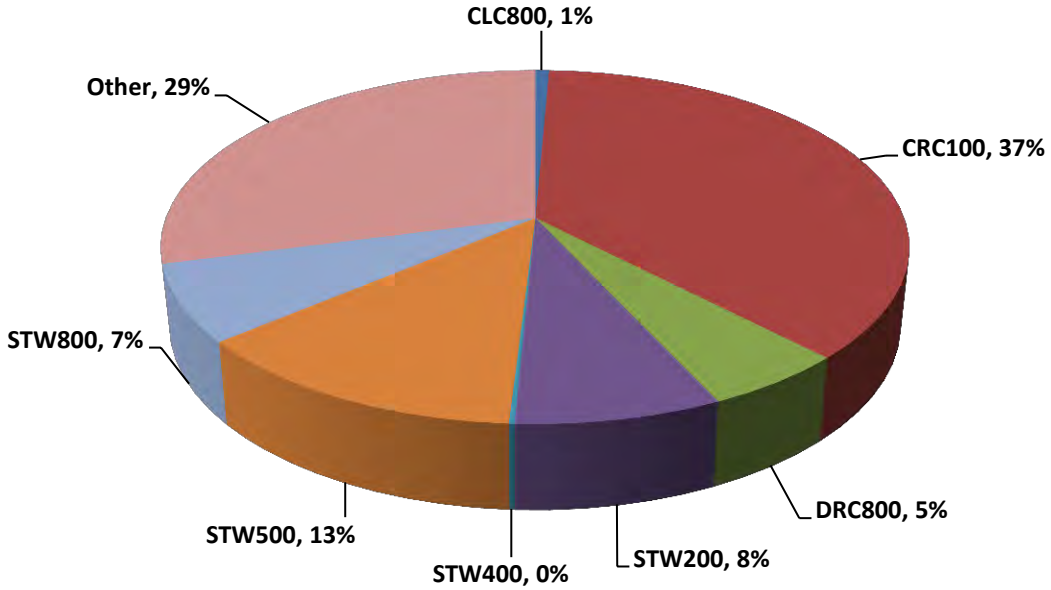

Figure 1–7. Percent Flow Volume Contribution at CRC800.

Boxplots were created by using the data available from mainstem and secondary sites that showed the range of TSS concentrations (milligrams per liter [mg/L]) at each site during various flow conditions. Secondary sites consist of tributary and stormwater sites. Boxplot trends are discussed in the following paragraphs and illustrated in the following figures. The first set of boxplots represents all TSS samples, and the second and third sets of boxplots separate the samples between base flow and event flow. For the purpose of this project's sampling, base flow is defined as flow that does not occur during, or shortly after, a precipitation event, and event flow is defined as flow that occurs during, or shortly after, a precipitation event. These boxplots reflect only the suspended sediment fraction of the total load and will generally not include the coarser fractions, such as coarse sands and fine gravels that constitute the majority of the excess sediment load that some storm drains contribute in Crow Creek.

All data at mainstem and secondary sites are provided in the first set of boxplots in Figure 1-8. Mainstem sites are shown in the top portion of Figure 1-8, and secondary sites are shown in the bottom portion of the figure. The mainstem Crow Creek monitoring site at Round Top Road (CRC100) is upstream from the impaired reach, and all other gages are within the impaired reach. The median TSS concentration increases fivefold between Round Top Road

Table 1-4. Summary of Total Suspended Solids Data in the Crow Creek Total Maximum Daily Load Study Area (Not Including Replicates)

Reach	Monitoring Stations	Project I.D.	First Sample Date	Last Sample Date	No. of Samples	Type
Upstream of Impaired Reach	Crow Creek near Round Top Road	CRC100	05/09/2010	09/21/2011	45	Grab, Integrated
Impaired Reach	Crow Creek near F.E. Warren Air Force Base	CRC300	05/09/2010	09/21/2011	55	Grab, Aliquot, Flow-Weighted Composite, Integrated
	Crow Creek near County Road 51 (downstream of Super America drain)	CRC350	05/18/2011	05/31/2011	6	Grab, Integrated
	Crow Creek near Martin Luther King Park	CRC400	05/09/2010	09/21/2011	49	Grab, Integrated
	Capitol Basin Outfall	STW200	05/10/2010	09/21/2011	64	Grab, Aliquot, Flow-Weighted Composite, Integrated
	Clear Creek at Confluence	CLC800	05/10/2010	09/21/2011	49	Grab, Integrated
	Crow Creek near Deming Drive	CRC500	05/10/2010	09/21/2011	66	Grab, Aliquot, Flow-Weighted Composite, Integrated
	South Park	STW380	04/18/2011	9/21/2011	19	Grab
	"Other" U.P. Outfall	STW400	05/12/2010	08/04/2011	28	Grab, Flow-Weighted Composite, Integrated
	South 15th Drain	STW430	05/10/2011	08/03/2011	7	Grab
	Crow Creek near 1st Street	CRC600	05/10/2010	09/21/2011	69	Grab, Aliquot, Flow-Weighted Composite, Integrated
	Morrie Avenue Outfall	STW500	05/10/2010	09/21/2011	55	Grab, Flow-Weighted Composite, Integrated
	Crow Creek near Morrie Avenue	CRC650	05/18/2011	06/02/2011	6	Grab, Integrated
	Crow Creek Upstream of WWTP	CRC700	05/10/2010	09/21/2011	63	Grab, Aliquot, Flow-Weighted Composite, Integrated

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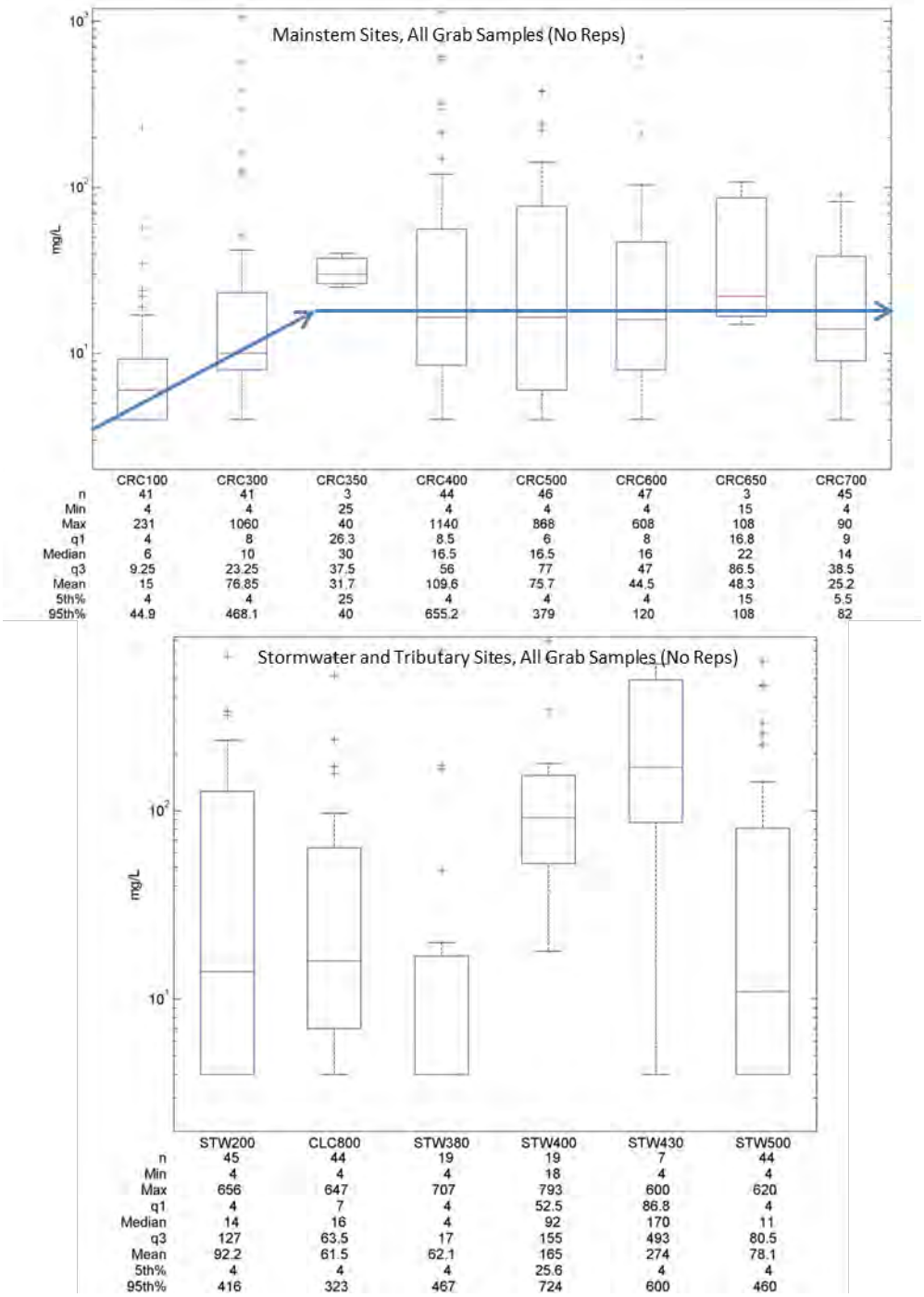


Figure 1–8. Total Suspended Solids Concentration Boxplots for Combined Base Flow and Event Flow From the Mainstem Sites (Upper Boxplots) and Tributary and Stormwater Sites (Lower Boxplots) in the Project Area.

and County Road 51 (CRC350). From this point, the concentration slightly decreases and remains fairly constant throughout the rest of the impaired reach. Although secondary sites "Other" U.P. Outfall (STW400) and the South 15th Drain (STW430) have very high median sediment concentrations when compared to other sites, they do not seem to have an impact where they flow into Crow Creek between Deming Drive (CRC500) and 1st Street (CRC600). The higher median concentrations at County Road 51 (CRC350) and Morrie Avenue (CRC650) are based upon only three samples and may not be as representative of actual conditions as those at other sites. Note that CRC300 is very near the best attainable urban condition site (Happy Jack Road) from the original WDEQ assessment [Hargett, 2009], which is discussed further in Chapter 2.0.

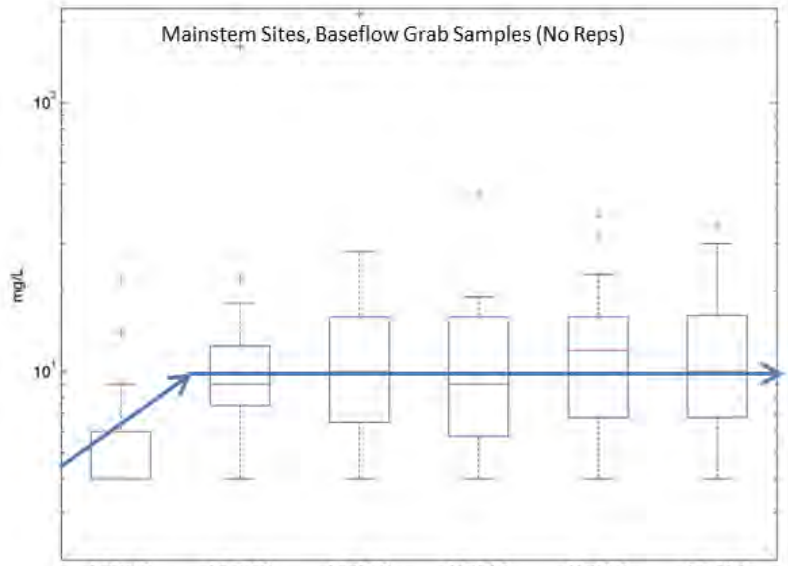
The Base flow trends at mainstem sites (upper boxplots) and secondary sites (lower boxplots) are provided in Figure 1-9. Median concentrations during base flows increase slightly between Round Top Road (CRC100) and F.E. Warren Air Force Base (CRC300). From this point, the concentrations remain fairly constant throughout the remainder of the project area. The "Other" U.P. Outfall (STW400) and the South 15th Drain (STW430), which both flow into Crow Creek between Deming Drive (CRC500) and 1st Street (CRC600), seem to impact TSS concentrations at 1st Street. Sediment concentrations during base flows generally remain below 30 mg/L.

The event flow trends at mainstem sites (upper boxplots) and secondary sites (lower boxplots) are shown in Figure 1-10. Median event flow concentrations increase from Crow Creek near Round Top Road (CRC100) to Crow Creek near Martin Luther King Park (CRC400). These increases can possibly be attributed to Capitol Basin (STW200) and Clear Creek (CRC800). After Martin Luther King Park, median concentrations remain fairly constant throughout the rest of the city. Although secondary sites "Other" U.P. Outfall (STW400) and the South 15th Drain (STW430) have higher median sediment concentrations compared to other sites during stormflows, they do not seem to have an impact where they flow into Crow Creek between Deming Drive (CRC500) and 1st Street (CRC600). Median concentrations during event flows tend to be above 30 mg/L and are far higher than median concentrations during base flows.

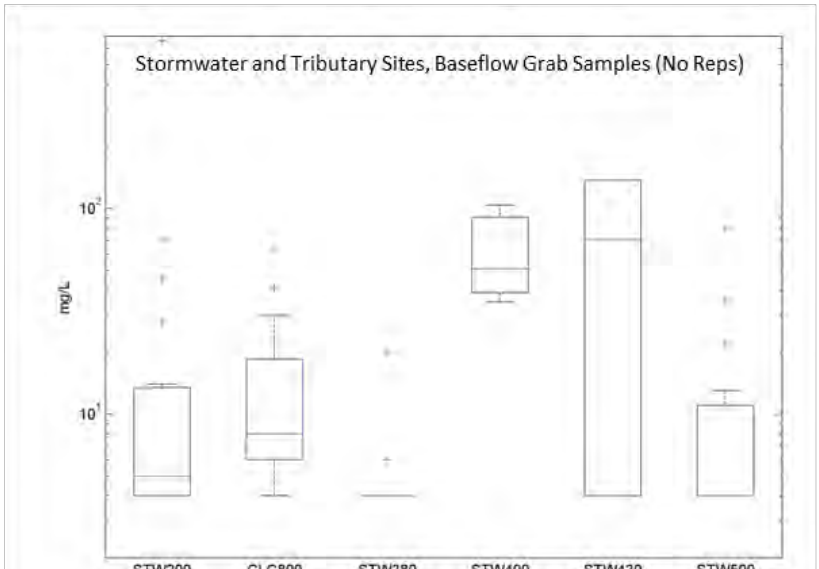
1.6.2 Bedload Data

Bedload sampling was completed specifically for this project from March to October 2011. Because sediment delivery to Crow Creek mainly occurs in pulses during small episodic storms, the sampling team responded to reported Crow Creek flows at the 19th Street gage in excess of 30 cfs. Additionally, bedload traps were installed to monitor low sediment flows (< 30 cfs) in at CRC500 and CRC700. The bedload traps collected negligible sediment at flows less than 30 cfs.

The bedload sampling was performed with a 3-inch Helley-Smith bedload sampler with a 3.22 area ratio. Bedload measurements are presented for the sampling sites at Westland Road (representative of the upstream supply) and Morrie Avenue (the TMDL endpoint) in Figures 1-11 and 1-12, respectively.

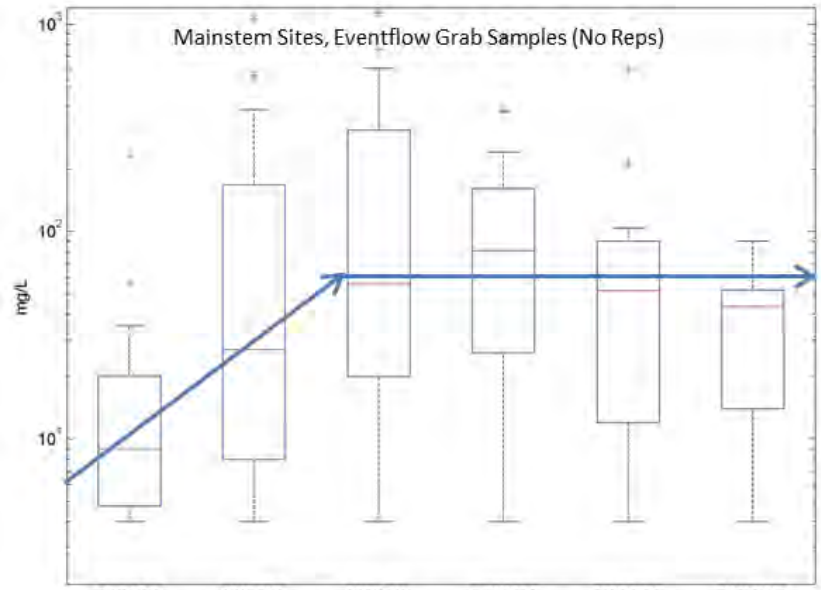


	CRC100	CRC300	CRC400	CRC500	CRC600	CRC700
n	24	24	24	25	25	25
Min	4	4	4	4	4	4
Max	22	162	214	46	38	35
q1	4	7.5	6.5	5.75	6.75	6.75
Median	6	9	10	9	12	10
q3	6	12.5	16	16	16	16.3
Mean	6.46	16.6	20	12.7	13	13
5th%	4	4	4	4	4.75	5.5
95th%	16.4	64	83.8	46	33.5	31.3

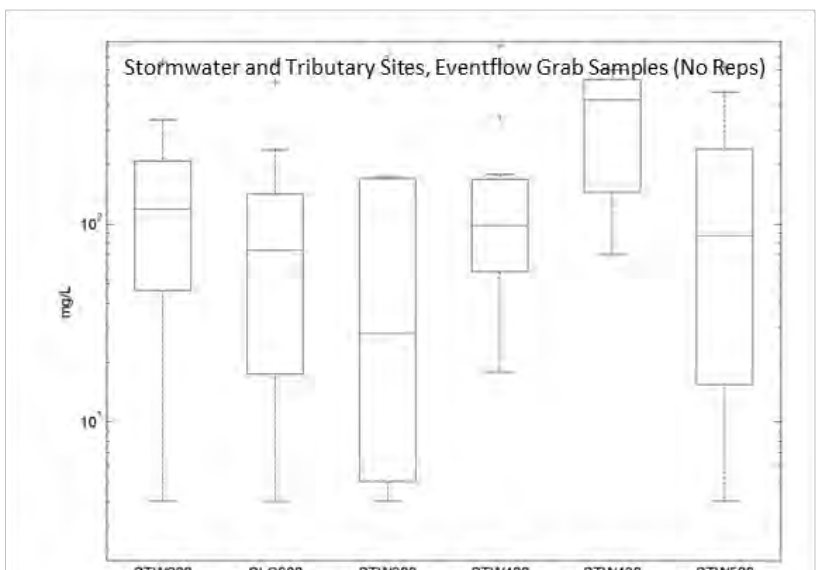


	STW200	CLC800	STW380	STW400	STW430	STW500
n	24	25	11	3	2	24
Min	4	4	4	35	4	4
Max	654	64	20	104	137	80
q1	4	6	4	39	4	4
Median	5	8	4	51	70.5	4
q3	13.5	18.5	4	90.8	137	11
Mean	38.6	14.3	5.64	63.3	70.5	11.1
5th%	4	4	4	35	4	4
95th%	245	46.8	19.3	104	137	49.2

Figure 1–9. Total Suspended Solids Concentration Boxplots for Base Flow From the Mainstem Sites (Upper Boxplots) and Tributary and Stormwater Sites (Lower Boxplots) in the Project Area.



	CRC100	CRC300	CRC400	CRC500	CRC600	CRC700
n	17	17	20	21	22	20
Min	4	4	4	4	4	4
Max	231	1060	1140	868	608	90
q1	4.75	8	20	26	12	14
Median	9	27	56	81	52	43.5
q3	20.3	168.3	308	162	90	52.5
Mean	26.9	161.9	217.1	151	80.3	40.5
5th%	4	4	4	4	4	5.5
95th%	170	887.1	948	601	370	86



	STW200	CLC800	STW380	STW400	STW430	STW500
n	21	19	8	16	5	20
Min	4	4	4	18	70	4
Max	656	647	707	793	600	620
q1	46.3	17.5	5	57.5	145	15.5
Median	119	74	28	98.5	424	87
q3	209	142	170	168	537	240
Mean	153	124	140	184	356	158
5th%	4.55	4	4	23.4	70	4
95th%	480	590	707	747	600	542

Figure 1–10. Total Suspended Solids Concentration Boxplots for Event Flow From the Mainstem Sites (Upper Boxplots) and Tributary and Stormwater Sites (Lower Boxplots) in the Project Area.

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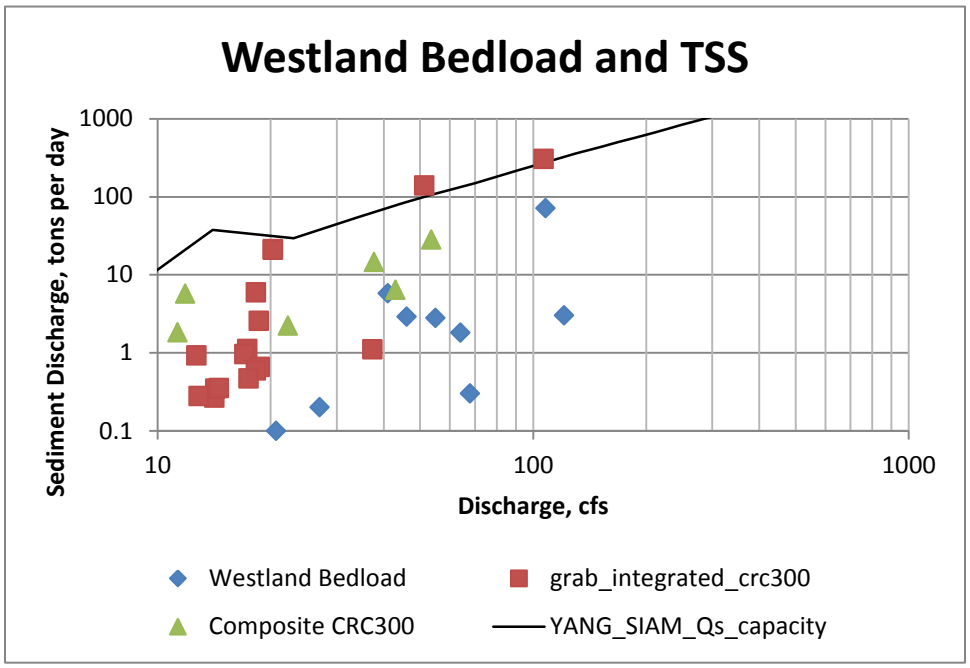

Figure 1–11. Westland Road Bedload, Total Suspended Solids Sample Data and Predicted Instantaneous Sediment Transport Capacity.

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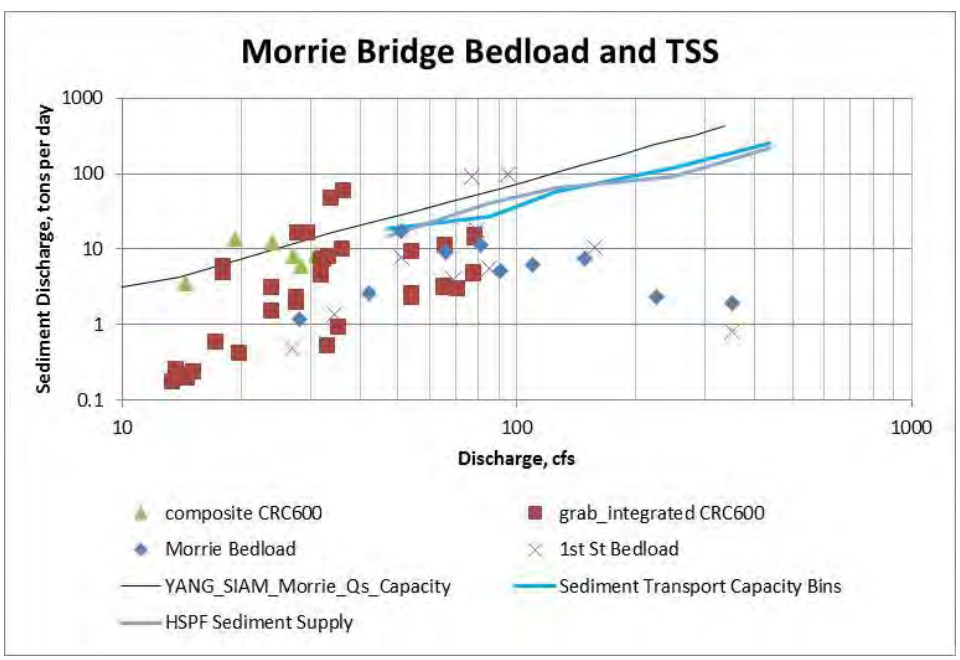

Figure 1–12. 1st Street and Morrie Avenue Bedload and Total Suspended Solids Sample Data Compared to the Predicted Instantaneous Sediment Transport Capacity, the Predicted 24-Hour Event-Average Sediment Supply, and the 24-Hour Event Average Sediment Transport Capacity.

1.6.3 Bed Material and Floodplain Data

Bed material and floodplain sediment samples were collected on August 19, 2010, to characterize the reach bed material gradation. The bed material samples were collected from the channel at five locations: (1) downstream of the I-25 bridges, (2) below the Ames Avenue Street Bridge, (4) just upstream of the Morrie Avenue Bridge, and (5) upstream of the Haystack Farm Road Bridge. Two floodplain samples were collected as well: one on the inset left bank floodplain upstream of the I-25 bridges and one on the left bank floodplain just downstream of the West 1st Street Bridge.

Figure 1-13 illustrates the grain size distribution for all the samples. Note the following three comparisons:

1. The floodplain sediment sample upstream of I-25 to the bed sediment sample collected upstream from the Morrie Avenue Bridge: Both samples have similar grain size distributions and are finer-grained than the other samples. This is likely caused by the upstream backwater sedimentation that is associated with constrictions from old bridges at these locations.
2. The bed samples collected downstream of the I-25 bridges at Martin Luther King Jr. Park and upstream of the Haystack Farm Road Bridge with the floodplain sample collected just downstream of the West 1st Street Bridge: These samples also have similar grain size distributions, which suggests that the sediment that enters the upstream end of the project reach is no different from the sediment that is contributed to, and passes through, the middle of the reach and into the lower part of it. In addition, the sediment that is contributed to the creek is easily transported through it, if flows are of a sufficient magnitude and duration necessary to mobilize the sediment.
3. The bed samples collected near the O'Neil Avenue and Deming Drive intersection near stream gage CRC500 to the bed sample collected upstream of the West 1st Street Bridge: Both sites represent a channel that has been rerouted and artificially modified. The O'Neil-Deming site is within the section of the creek that was moved 1,400 feet south of its current location. The channel and floodplain are part of a floodway excavated at this location. The site upstream of the West 1st Street Bridge was part of a channel that was rerouted from the east side of the floodway to the west side of the floodway upstream of the bridge. The subsequent winnowing of fines from the top of the floodplain and from the channel bed resulted in coarser material left behind.

1.6.4 Geomorphic Assessment

A geomorphic assessment of Crow Creek, presented in Appendix B, was completed based on the field reconnaissance of the creek, sediment sampling conducted at a number of sites along the creek, examining historic flow records and anecdotal accounts of floods on the creek and surveyor's notes from General Land Office (GLO) surveys conducted in 1870, and comparing

historic maps and aerial photography. The geomorphic assessment was performed to provide information on the relative significance of potential in-channel sediment sources to ensure that the previous **HEC-RAS** model created for Crow Creek was still valid and to provide additional data for updates for the current **HEC-RAS** modeling effort (described further in Section 4.1). Based on the analysis, the current channel is the product of extensive channel and floodway modification and the subsequent channel adjustments to those modifications over the last 140 years. Those adjustments included channel degradation and widening and the possible localized armoring of the channel bed. The assessment found that in-channel storage of sand and fine gravel occurs throughout Crow Creek but is most notable at and immediately upstream of constrictive crossings and below major stormwater outfalls. The current bed substrate material leads to in stream channel substrate that is unfavorable for the biotic community as defined by the WDEQ [Harget, 2009], which is the reason for the Crow Creek impairment.

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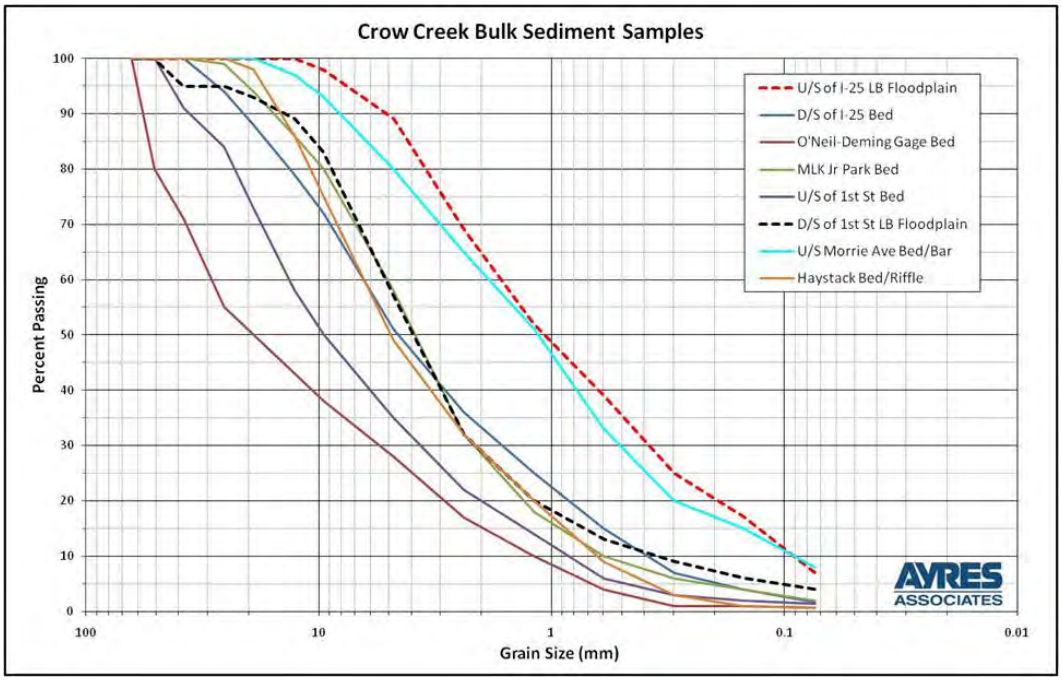

Figure 1–13. Grain Size Distributions of Bulk Sediment Samples Collected From the Bed and Floodplain of Crow Creek.

2.0 LINKAGE ANALYSIS

The WDEQ assessment [Hargett, 2009] identified the reach from Happy Jack Road to Hereford Reservoir #1 as having excess sediment, most of which originates between Deming Drive and Morrie Avenue. Sediment sources include stormwater runoff from industrial, commercial, and residential properties; construction sites; unvegetated areas; and sand and gravel application to streets and highways. The sediment is delivered in pulses to the stream through the stormwater drains and direct entry. Bank erosion in the impaired reach was minor and localized. The excess sediment in Crow Creek (primarily in the form of excess bed material load) caused excessive deposition throughout the impaired segment, which was most notable upstream of restrictive crossing features and immediately downstream of storm drain outfalls. This excessive deposition resulted in a localized shallowing and widening of the stream channel, which impacted stream habitat quality. The sediment supply pulses resulted in high rates of channel turnover and excess substrate mobility. Physical evidence of excess sediment mobility was more pronounced with distance downstream from Happy Jack Road.

In addition to sediment, other physical and chemical characteristics were evaluated in Crow Creek. The aquatic ecology in Crow Creek was determined to be impaired as a result of excess sediment, high selenium, *E. coli*, and high water temperatures [Hargett, 2009]. The following discussion focuses on excess sediment and its impact on the aquatic life use attainment of Crow Creek. Hargett [2009] linked excess sediment in Crow Creek and the decline in the biological condition by evaluating the benthic macroinvertebrate community. Generally, the WSII and WY RIVPACS scores declined with the distance downstream from Happy Jack Road to Morrie Avenue. In 2008, the WY RIVPACS scores were lower at Deming Drive and Morrie Avenue than at Happy Jack Road. The WSII and WY RIVPACS scores from 2007 and 2008 are provided in Table 2-1.

Table 2-1. Crow Creek WSII and WY RIVPACS Scores

Site→	Happy Jack Road		Deming Drive		Morrie Avenue	
Year→	2007	2008	2007	2008	2007	2008
WSII Score	37.3	38.6	34.5	34.1	28.3	24.4
WY RIVPACS Score	0.55	0.55	0.55	0.33	0.55	0.33

The lower scores were primarily from an overall loss of taxa, an increase in abundance of tolerant to highly tolerant taxa, and an increase in the abundance of collector-gatherers. Excess sediment mobility, deposition, and nutrient enrichment can favor the relative abundance of collector-gatherers. The declines in the WSII scores and WY RIVPACS scores with distance

downstream indicate a degradation of the biological condition, which occurs with a trend of increasing sedimentation.

Individual benthic macroinvertebrate metrics were also evaluated. The following selected observations provide evidence of the linkage between sedimentation and biological condition:

- The overall benthic macroinvertebrate density declined approximately 83 percent from Happy Jack Road downstream to Morrie Avenue in 2007 and declined approximately 68 percent from Happy Jack Road downstream to Morrie Avenue in 2008. Increased anthropogenic stress typically causes decreases in macroinvertebrate density [Barbour et al., 1999; Lenat et al., 1981]. Hargett [2009] states that "considering the chemical and physical data, these data suggest that environmental stressors such as excess sediment deposition that degrades aquatic habitat may be responsible for the decline in density from Happy Jack Road to Morrie Avenue."
- The number and relative abundance of nonmidge fly larvae declined with distance downstream from Happy Jack Road, and the largest decreases occurred between Happy Jack Road and Deming Drive. The decline in this metric was from the loss of moderately tolerant, nonmidge fly larvae such as the black fly larvae *Simulium*. *Simulium* need stable, coarse substrate for attachment [Relyea et al., 2000; Voshell, 2002]. The fine gravel particles in Crow Creek are highly mobile, which prevents *Simulium* from attaching to the substrate and establishing stable populations. *Simulium* declined from a mean relative abundance of 29 percent at Happy Jack Road to 7 percent at Deming Drive and 1 percent at Morrie Avenue.
- The relative abundance of oligochaetes, or aquatic worms, increased with distance downstream, and high increases occurred between Happy Jack Road to Morrie Avenue. The aquatic worm's relative abundance increased from 2 percent at Happy Jack Road to 14 percent at Deming Drive and 19 percent at Morrie Avenue. These increases were mostly from Tubificid worms. This pattern is typically seen in streams that are stressed by excess sediment deposition and/or organic nutrient enrichment [Anlauf and Moffitt, 2008; Barbour et al., 1999; Lenat et al., 1981; Mikalsen, 1989].
- In 2007, Hydroptilid caddisflies declined in relative abundance between Happy Jack Road (8 percent), Deming Drive (3 percent) and Morrie Avenue (0.2 percent), and in 2008 they were only found at Happy Jack Road. The relative abundance of caddisflies in general has been found to decrease with increased sedimentation and substrate instability [Cobb and Flannagan, 1990]. The Hydroptilid caddisfly diet consists exclusively of filamentous algae that attaches firmly to coarse substrate [Ward, 1992]. The observed decline in Hydroptilid caddisflies is likely from a loss of filamentous algae associated with a mobile channel bed.
- The midge genus Cricotopus represented a substantial component of the benthic macroinvertebrate community and the highest abundances occurred at Deming Drive, Morrie Avenue, and Haystack. Cricotopus are tolerant to a wide range of environmental

extremes and, more specifically, have been shown to tolerate excess sediment deposition [Lenat, 1979].

Canonical Correspondence Analysis was used to identify groupings of sites with similar relative abundances of benthic macroinvertebrate species. The correlations of environmental variables with the Canonical Correspondence Analysis results were then used to determine which environmental variables explained most of the variability in the macroinvertebrate communities. The Canonical Correspondence Analysis results showed downstream departures from the best attainable macroinvertebrate assemblage at Happy Jack Road. Variability in nine environmental factors explained approximately 60 percent of the variance among the benthic macroinvertebrate assemblages identified in the Canonical Correspondence Analysis. Four of the nine environmental factors are surrogates for excess sedimentation. Overall, the results of the Canonical Correspondence Analysis suggest that excess sediment, nutrient enrichment, and low dissolved oxygen influence the benthic macroinvertebrate communities in Crow Creek. Overall, the WDEQ assessment evaluated the physical, chemical, and biological data and determined that excess sediment is one of the primary stressors of the benthic macroinvertebrate community that leads to nonattainment of fisheries and other aquatic life designated uses [Hargett, 2009].

The allowable bed material load in this TMDL was based on the sediment transport capacity of Crow Creek. If total bed material sediment supply is reduced below the current sediment transport capacity to the target discussed in this TMDL, the system will tend to flush existing in-channel deposits. The bed material sediment supply from the urbanized region of the impaired reach largely consists of sand and fine gravel. If the supply reduction is primarily from the urbanized reach sediment supply, then the stream will tend to flush existing sand and fine gravel material from the bed and leave a more coarse-grained substrate that is closer to the upstream best attainable urban condition at Happy Jack Road. Also, limiting the sediment reduction to modest bed sediment supply reduction and combining it with a robust monitoring protocol will reduce the likelihood of undesirable excess degradation and terrace formation and initiate channel rejuvenation cycles. The resulting higher quality habitat will improve the biological condition directly through improved benthic macroinvertebrate condition. This improvement will impact higher trophic levels and the fish assemblage will recover as a result of higher quality food sources. These changes in the biological condition will ultimately lead to the attainment of fisheries and other aquatic life-designated uses of Crow Creek, and it is expected that the WSII and WY RIVPACS scores will eventually fall between the range that occurs between Happy Jack Road and Deming Drive and, therefore, will be classified as fully supporting its designated use.

3.0 SIGNIFICANT SOURCES

Sediment sources in the Crow Creek project area are a factor of both point-source and nonpoint-source pollution. The sediment impairment in Crow Creek is driven by excess bed material sediment load. Bed material load includes all transported material present in the bed of an alluvial channel. It is transported as either bedload or as suspended load. Hargett [2009] identified the excess sediment supply as a constituent linked to nonattainment of designated uses on Crow Creek. The permitted point sources include the MS4, construction, industrial, and mine permits that contribute sediment to Crow Creek through rainfall runoff processes. Nonpoint sources contribute sediment through washoff outside of the permitted areas.

3.1 POINT SOURCES

Three Wyoming Pollutant Discharge Elimination System- (WYPDES-) permitted point sources, including the Crow Creek WWTP (WY0022381), the Cheyenne Board of Public Utilities Water Treatment Plant (WY0031721), and Frontier Oil Refinery (WY0000442), have numeric TSS criteria and discharge to, or upstream of, the impaired reach. Because point-source permittees settle out TSS and flows from point sources are not relatively high, point sources are not considered a source of bed material load. Therefore, they are not included in the wasteload allocation (WLA). The Cheyenne Parks and Recreation Department (WY0094617) and the Cheyenne Rail Yard Union Pacific Railroad (WY0000647) are also located in close proximity to, or upstream of, the impaired reach. These facilities do not have numeric TSS criteria in their permits, but their permits do state, "there shall be no discharge of floating solids or foam in other than trace amounts. Nor shall the discharge have a visible sheen or cause formation of a visible sheen or visible deposits on the bottom or shoreline of the receiving water [City of Cheyenne Parks and Recreation Department, 2011; Union Pacific Railroad, 2006]." Therefore, the Cheyenne Parks and Recreation Department and the Cheyenne Rail Yard Union Pacific Railroad are also not included in the WLA. The Dry Creek WWTP (WY0022934) is located downstream of the impaired reach and is, therefore, not addressed in this TMDL. Permitted point sources are illustrated in Figure 3-1.

An MS4 permit is a municipal stormwater discharge permit that authorizes the discharge of stormwater from municipal separate storm sewer systems. An MS4 permit exists in the project area which includes the Cheyenne, Wyoming, urbanized area as defined by the 2000 Census [Wyoming Department of Environmental Quality, 2008a]. The current MS4 permit was issued on December 1, 2008, and will expire on September 30, 2013 [Sahl, 2012a]. Its boundary includes the MS4s of the city of Cheyenne, Laramie County (portions within the urbanized area); Warren Air Force Base; and the Wyoming Department of Transportation—Cheyenne. Stormwater management programs are required to meet the applicable requirements of any TMDL on waters that will receive discharges from the MS4 [Sahl, 2012a].

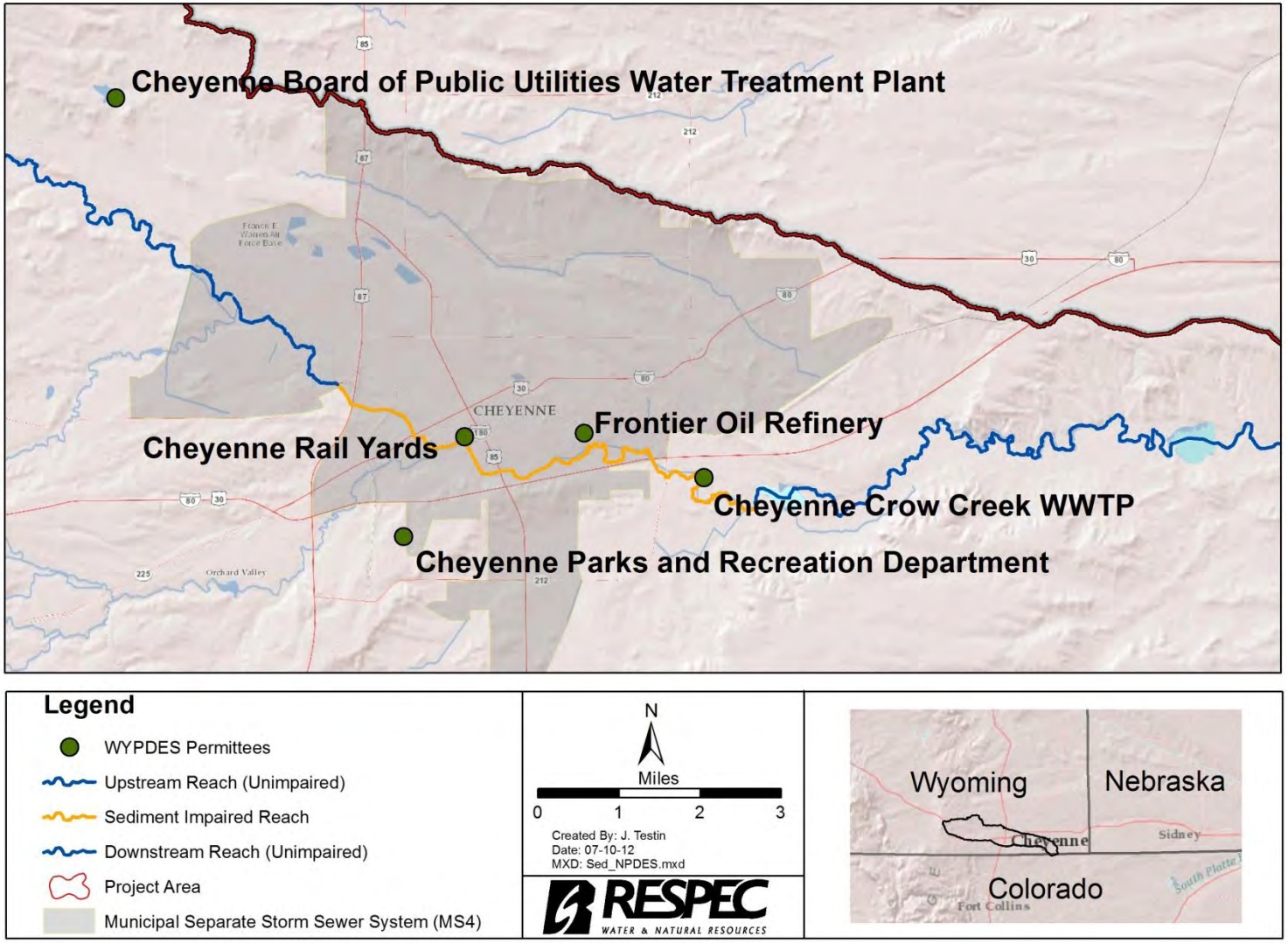

Figure 3–1. Point-Source Permittees, Including the MS4, Within the Crow Creek Project Area.

In addition to the point sources and the general MS4 permit, there is also a Large Construction General Permit (LCGP), a Small Construction General Permit (SCGP), a Mineral Mining General Permit (MMGP), and an Industrial General Permit (IGP) [Sahl, 2012a]. Laramie County has 57 construction permits, 16 mining permits, and 26 industrial permits. Temporary permits in Laramie County mainly consist of construction site dewatering. Temporary permits also cover the release of hydrostatic test water, swimming pool discharges, and potable water line flushing [Sahl, 2012b].

The Wyoming LCGP was renewed on May 9, 2011, and will expire March 15, 2016. It covers all construction projects that disturb 5 or more acres and smaller projects that are part of a common plan of sale or development that will disturb 5 or more acres. The LCGP requires applicants to note if they are within 2,000 feet and may discharge to a surface water of the state that is either on the 303(d) list because of impairment for excess sediment or turbidity or has an approved TMDL for excess sediment or turbidity. Stormwater Pollution Prevention Plans (SWPPPs) covering sediment controls for all projects that fall within this category are reviewed. Flow to municipal storm drain systems that discharge to sediment- or turbidity-impaired waters on the 303(d) or that have an approved TMDL, are not allowed the greater-than-2,000-foot exclusion from the SWPPP review [Sahl, 2012a].

The Wyoming SCGP recently expired but has been administratively extended. It covers all construction projects that disturb between 1 and 5 acres. Projects smaller than 1 acre will require coverage if they are part of a common plan of sale or development that will disturb between 1 and 5 acres. The SCGP is a "no application" permit for which coverage is achieved by complying with all components of the permit. The renewed permit will be very similar to the LCGP, except for the application requirement [Sahl, 2012a].

The Wyoming MMGP was renewed on April 1, 2012, and will expire March 31, 2017. It covers all mines regardless of size, except metal ore mines and coal mines. Permittees are required to update their SWPPPs to meet the new permit requirements. The new version of the the MMGP requires projects to submit a SWPPP regarding sediment control for review that (1) may be discharging to surface water of the state, (2) are either on the 303(d) list because of impairment for excess sediment or turbidity, or (3) have an approved TMDL for excess sediment or turbidity.

The Wyoming IGP was reissued on September 1, 2012, and will expire August 31, 2017. It covers manufacturing, transportation, junk and salvage yards, metal ore mining, and coal mining. The IGP does not cover commercial or retail operations. It is similar to the LCGP in relation to projects that may discharge to the state's surface waters on the 303(d) list [Sahl, 2012a].

3.2 NONPOINT SOURCES

Nonpoint-source pollution generally comes from channel degradation, surface runoff, and bed and bank erosion. Gravel/sand alleyways, gravel parking lots, private and public lands with

minimally vegetated steep slopes, construction projects less than 1 acre, and other similar sources have been occurring since the assessment to the present. Once sediment from these sources are delivered to the MS4, they then become part of the permitted load and are accounted for as a part of the WLA.

Another possible nonpoint source would include sand application for winter/precipitation/ice events when the temperature is below freezing. Although extensive road sanding has occurred in the past, the city of Cheyenne has indicated that it currently only applies approximately 300 tons of sand and gravel to the roadway once after the first major storm (usually in January), and that much (approximately two-thirds) of what is applied is picked up by street sweepers immediately after the snow melts. For subsequent storms, ice slicer (magnesium chloride) is applied at approximately 200 pounds per lane mile to the roadways when the temperature is below freezing [Nemecek, 2011]. The geomorphic assessment section of this TMDL document (Section 1.6.4) further discusses nonpoint-source pollution occurring in Crow Creek.

3.3 SOURCE ASSESSMENT

An **HSPF** model application was developed for the project area to determine the contribution of bed material sediment from identified sources and to evaluate different scenarios of implementing best management practices (BMPs) to control these sources. The Crow Creek drainage basin was represented in the model by using 39 subwatersheds and one boundary condition, which represented the confluence of North Fork Crow Creek and Middle Fork Crow Creek. **HSPF** is a comprehensive watershed model of hydrology and water quality that includes modeling both land surface and subsurface hydrologic and water-quality processes that are linked and closely integrated with corresponding stream and reservoir processes. **HSPF** is considered a premier, high-level model among those currently available for comprehensive watershed assessments. Because the model is continuous, the framework can be used to determine the critical environmental conditions (e.g., flow variable and seasonal) for the impaired reach by providing continuous flow and load predictions at any point in the system. For the Crow Creek TMDL project, event mean TSS concentrations for stormwater runoff events were used to calculate the average loading rates of TSS to Crow Creek. EMCs for the watershed are provided in Table 3-1. Once the TSS model application was calibrated, the regression equations that are further discussed in Section 3.3.1.3 were used to convert TSS to bedload. These bedload predictions were used to assess the predicted sediment supply versus the predicted sediment transport capacity to Crow Creek. The **HSPF** model application was used to develop a continuous time series of flow and TSS at the outlet of each subwatershed. It was also used for allocating sources and running large-scale BMP scenarios to identify cost-effective restoration strategies.

Table 3-1. Initial Event Mean Concentration Values

Site	Site Description	EMC (mg/L)
STW200	Capitol Basin Outfall	153
STW380	South Park	140
STW400	"Other" U.P. Outfall	184
STW430	South 15th Drain	356
STW500	Morrie Avenue Outfall	158

3.3.1 HSPF Model Methods

The primary components of developing an **HSPF** model application include the following:

- Collecting and developing time-series data.
- Characterizing and segmenting the watershed.
- Calibrating and validating the model.

The watershed model was first set up and calibrated to predict the range of flows that have historically occurred throughout the watershed, including the stormwater system, to assist in developing the load duration curves (LDCs). Subsequently, the watershed model application was used to predict TSS loadings. The modeling period was from 1995 through 2010; however, a higher weight was placed on the more recent data during calibration.

3.3.1.1 Collecting and Developing Time-Series Data

Data requirements for developing and calibrating an **HSPF** model application are both spatially and temporally extensive. The data used in developing the model application included the following:

- Meteorological time series from within and near the project area
- Stream flow and water-quality boundary conditions throughout the project area
- Cross sections from channel geometry from a project-specific **HEC-RAS** model within the MS4 and from other sources outside of the MS4.

Continuous stream flow from gaging stations listed in Section 1.5 and TSS data from monitoring sites listed in Section 1.6 were used to calibrate the **HSPF** model application to existing, observed conditions. Precipitation, potential evapotranspiration, air temperature, wind speed, solar radiation, dew point temperature, and cloud cover are needed for **HSPF** to calculate hydrology (including snow processes). Flow and TSS from point sources were represented in the model.

In addition to the aforementioned data, observed flow and water-quality data are needed to compare and calibrate to simulated results. All TSS data collected from 2002 through 2010 were used to calibrate the **HSPF** model application.

3.3.1.2 Characterizing and Segmenting the Watershed

The watershed segmenting process divides the project area into individual land and channel segments, or pieces, that are assumed to demonstrate relatively homogenous hydrologic, hydraulic, and water-quality behaviors. This segmentation provides the basis for assigning similar or identical input and/or parameter values to all portions of a land area or channel length contained within a model segment. Because **HSPF** and most watershed models differentiate between land and channel portions of a watershed and each is modeled separately, each watershed undergoes a segmentation process to produce separate land and channel segments that are linked together to represent the entire watershed area.

The river reach segmentation requires considering river travel time, riverbed slope continuity, temporal and spatial cross sections, morphologic changes or obstructions, the confluence of tributaries, TMDL reach end points, and calibrating and verifying gage locations for flow and sediment. The municipal boundary and sewershed were also used to accurately represent the MS4. Once the segmentation was finalized, each reach segment was analyzed to compute the tributary areas of the land-use categories and the hydraulic characteristics of the reach. The reach hydraulic behavior is specified in a function table (F-table), which is an expanded rating curve that contains the reach surface area, volume, and discharge as functions of depth (i.e., an expanded rating curve). F-tables were developed for each reach segment by using Manning's equation, and based on cross-sectional data. Unsurveyed tributaries were assigned the geometry of hydraulically similar channels.

Land segmentation was used to assign unique parameters to areas of land within the **HSPF** model application. The Crow Creek model application has 42 land segments. For the land segmentation, the subbasins illustrated in Figure 3-2 were delineated to capture hydrologic and water-quality variability. Land segmentation was based on the boundaries defined by meteorological characteristics and land use. Land use and land cover affect the hydrologic and water-quality response of a watershed, and also infiltration, surface runoff, and water losses from evaporation or transpiration. The movement of water through the system is affected significantly by vegetation (e.g., crops, pasture, or open) and associated characteristics. The 2001 NLCD was integrated with a more high-resolution land cover of the city of Cheyenne from 2000. When the model was developed, these land cover layers were the most recent ones available. The resulting land cover categories were aggregated into seven model categories by combining hydrologically similar land cover categories to reduce complexity. The urban categories were divided into pervious and impervious areas based on an estimated percent (between 30 and 65 percent, depending on the urban category) of effective impervious area (EIA). The term "effective" implies that the impervious region is directly connected to a local

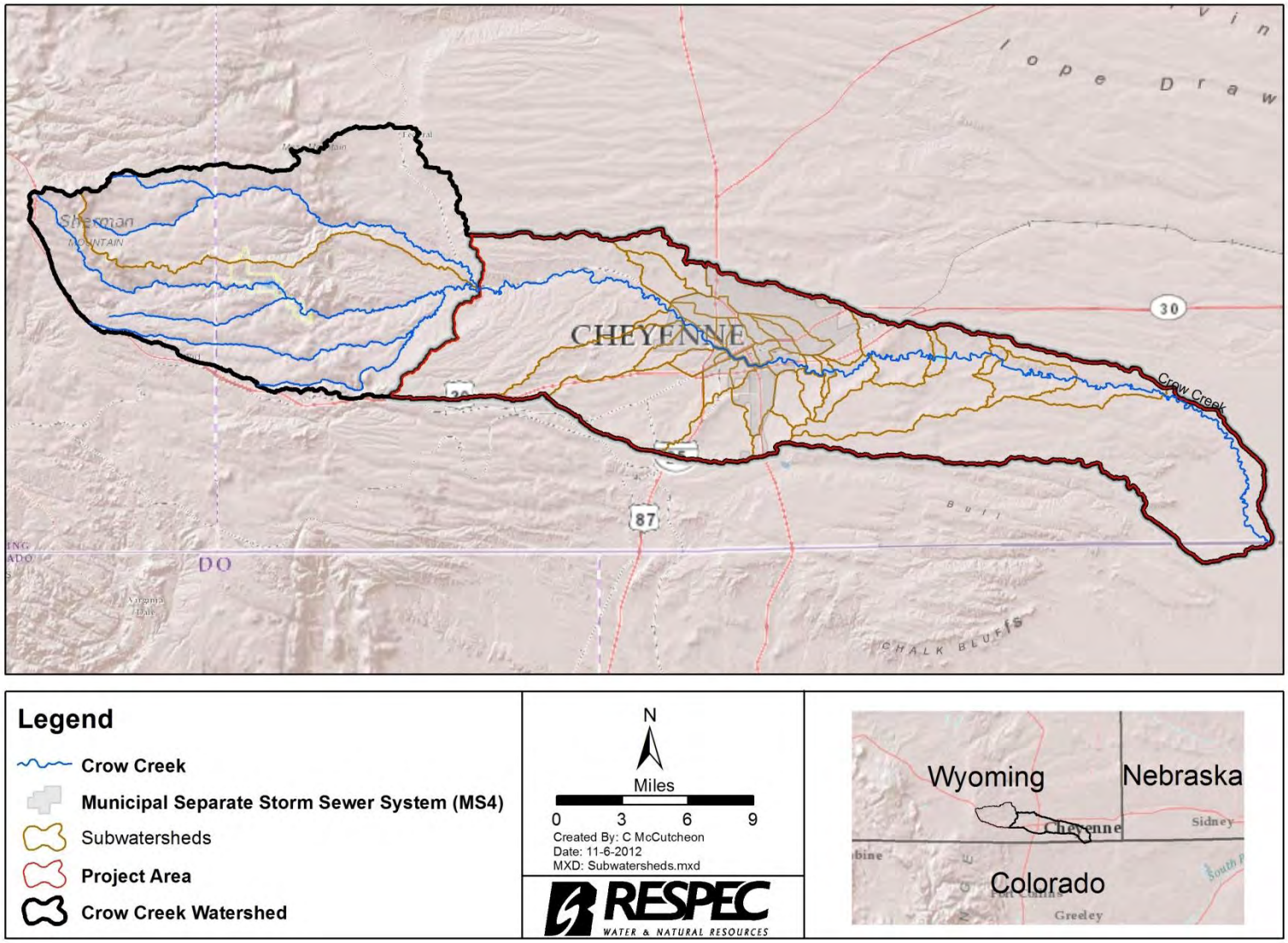

Figure 3–2. Crow Creek **HSPF** Subbasins.

hydraulic conveyance system (e.g., open channel or river), and the resulting overland flow will not run onto pervious areas and will not have the opportunity to infiltrate along its respective overland flow path before reaching a stream or waterbody.

3.3.1.3 Calibrating and Validating the Model

Hydrology

Once the initial model was developed, the calibration and verification process began. Time-series data used for hydrologic calibration included the long-term data from the USGS Gage 06755960 and 13 monitoring sites in 2010. For this project, the simulation period of 1996 through 2010 was used to calibrate the model. The initial year (1995) was simulated to allow the model to adjust to existing conditions. This time period (1996 to 2010) is a validation of the model because it had exceptionally wet years in the late 1990s to extreme drought conditions in the 2000s. Therefore, it validates the model response during both wet and dry time periods. An iterated boundary condition was used at the confluence of North Fork and Middle Fork Crow Creek to account for stream flow.

Hydrologic calibration is an iterative process intended to match simulated flow to observed flow by methodically adjusting model parameters. Water-quality simulations depend highly on the hydrology process. Therefore, water-quality calibration cannot begin until the hydrology calibration is considered acceptable. **HSPF** hydrologic calibration is divided into four sequential phases of adjusting appropriate parameters to improve performance and includes the following:

- Annual runoff
- Seasonal or monthly runoff
- Low and high flow distribution
- Individual storm hydrographs.

By iteratively adjusting specific calibration parameter values within accepted ranges, as outlined by the U.S. Environmental Protection Agency [2000], the simulation results are improved until an acceptable comparison of simulated results and measured data is achieved. The procedures and parameter adjustments involved in these phases are more completely described in Donigian et al. [1984] and Lumb et al. [1994].

The performance of modeled hydrology was evaluated by using a weight-of-evidence approach based on criteria developed from over 30 years of modeling experience with **HSPF**. These calibration and validation R and R^2 targets are illustrated in Figure 3-3. This approach uses a variety of graphical comparisons and statistical tests including annual and monthly runoff errors, low flow and high flow distribution errors, and storm volume and peak flow errors. More weight was given to the performance of the USGS gage, because it is a continuous daily flow for the entire model simulation period, and the other gages only provided data for less than a full year in 2010. The performance criteria are described in more detail in Donigian [2002].

Figure 3–3. Calibration and Validation R and R^2 Targets for **HSPF** Applications.

The model application simulates hydrology above Capitol Basin very well with daily and monthly coefficients of determination (R^2) of 0.91 and 0.97, respectively. Observing the gages downstream of Capitol Basin and the urbanized area, the performance of the model is good, and the daily R^2 values range from 0.73 to 0.98. Daily and monthly R^2 values at each mainstem gage are provided in Table 3-2.

Table 3-2. Mainstem Daily and Monthly R^2 Values

Site	Daily R^2
CRC100	0.98
CRC300	0.93
CRC400	0.91
CRC500	0.88
CRC600	0.93
CRC700	0.88
CRC800	0.88
CRC900	0.73

Sediment

Because **HSPF** model applications represent suspended sediment and not bedload, the model was calibrated to TSS data. The predicted **HSPF** TSS was converted to bedload supply rates for Crow Creek at Westland Road and for Crow Creek through the urbanized area using regression analyses. Bedload samples were paired with TSS samples for all available corresponding events. The resulting paired dataset was somewhat sparse; however, given the resources available for the sampling effort and the events sampled, this dataset represents the best-available method for relating TSS to bedload and, by extension, for relating the predicted long-term bed material supply to Crow Creek. Plots of the paired samples are presented in Figure 3-4. These samples were used to develop a bedload/TSS regression. The primary focus for the **HSPF** model application was to estimate the bedload supplied to the impaired reach, which was later compared to the bed material (total load) sediment transport capacity within Crow Creek.

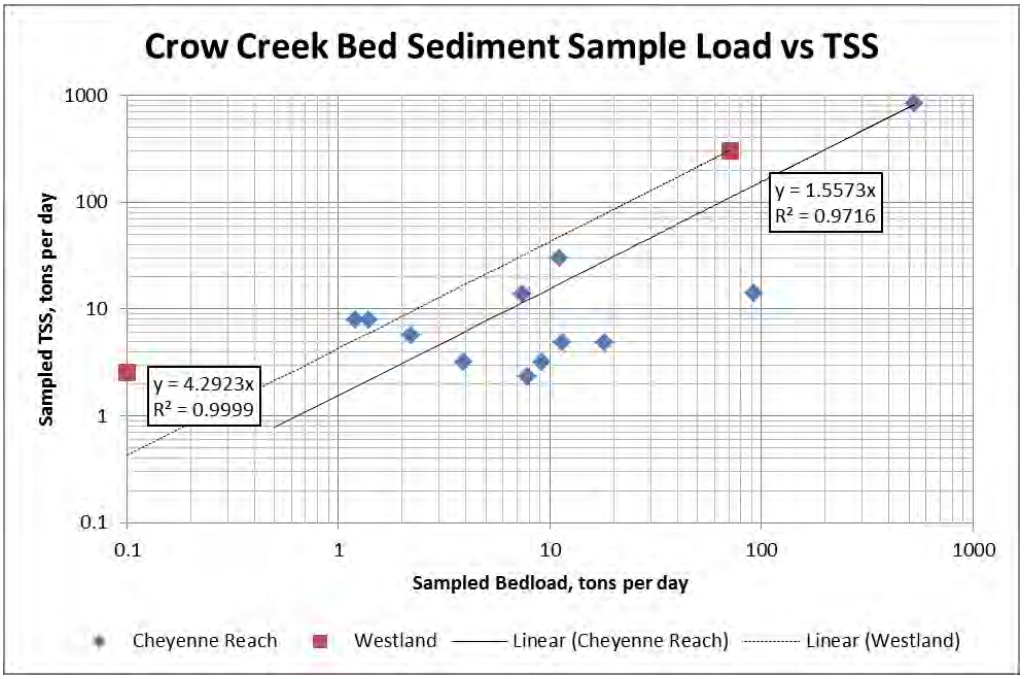

Figure 3–4. 2011 Crow Creek Sampled Bedload Versus Total Suspended Solids.

A boundary condition time series of suspended sediment was developed using **LOADEST**, which is a program that estimates constituent loads using regression models. Inputs to **LOADEST** include paired TSS and flow data as well as a continuous flow time series for which **LOADEST** calculates a continuous TSS time series by using the best fit regression equation. The EMCs represent TSS from overland flow in the model application and were adjusted based on the site-specific TSS concentration data (all aliquots, grabs, and flow-weighted composites on a daily average basis) collected throughout the project area. EMC values are adjusted to provide the initial input into the stream channel, and the calibration continues by adjusting the parameters governing the processes of deposition, scour, and the transport of sediments in the stream. Calibration is performed on a reach-by-reach basis from upstream to downstream, because upstream parameter adjustments influence downstream reaches. Sediment budgets are analyzed at each reach to ensure that the results are consistent with field observations and historical reports. Because observed data were not available at each reach, the calibration focused on locations where TSS concentration data were available. EMCs were adjusted as necessary during calibration to create the preferred concentrations and loadings based on observed data.

The model application represents TSS well. For the performance of the sediment calibration, a visual evaluation was used because the EMC method represents the average trends based on flow. Using statistics would be misleading because sediment is variable. Figures 3-5 and 3-6 illustrate the concentration duration curves for simulated and observed sediment upstream

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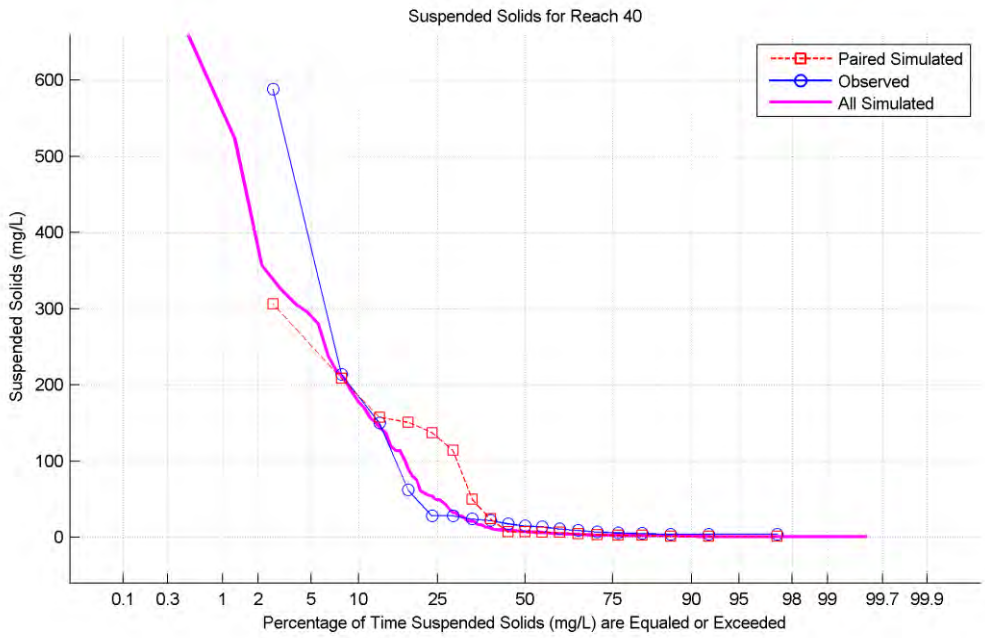

Figure 3–5. Simulated and Observed Total Suspended Solids Concentration Duration Curves Above Capitol Basin.

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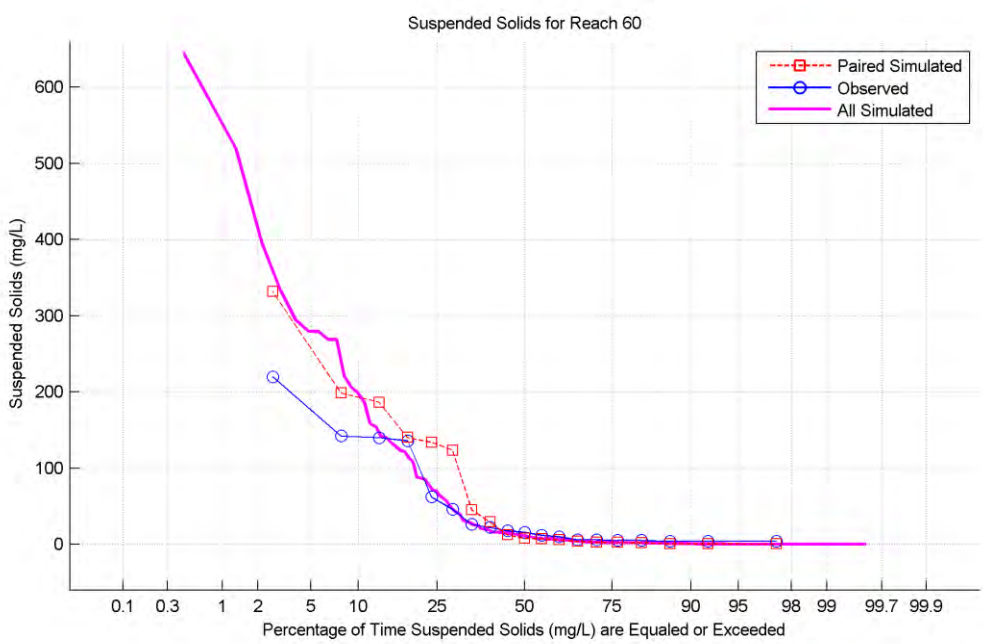

Figure 3–6. Simulated and Observed Total Suspended Solids Concentration Duration Curves Below Capitol Basin.

and downstream of Capitol Basin, respectively. Observed data are shown as blue circles, and the simulated results are represented with a solid pink line (all simulated) and red squares (paired simulated).

3.3.2 Source Assessment

Predetermining nonpoint sediment loading sources by using observed data, which is often limited, is difficult in an urban environment. The calibrated **HSPF** model application can help quantify source contributions when limited paired flow and concentration data are available, because it is built using continuous time series inputs that are applied to all contributing areas and because it accounts for land use throughout the project area. The calibrated **HSPF** model application is also highly effective in quantifying load contribution from a variety of point and nonpoint sources in a watershed. For this project, source assessment **HSPF** modeling results were summarized for urban and nonurban areas. Urban areas included the MS4 as well as construction, industrial, and mining activities occurring in the watershed. Nonurban areas included areas outside of the MS4. A time series of average daily loads occurring on each date from 1995 through the end of September 2010 by source from the model application was created. Figure 3-7 illustrates the breakdown between urban and nonurban TSS loads at the endpoint of the impaired reach. Source contributions were mainly from urban areas (95 percent).

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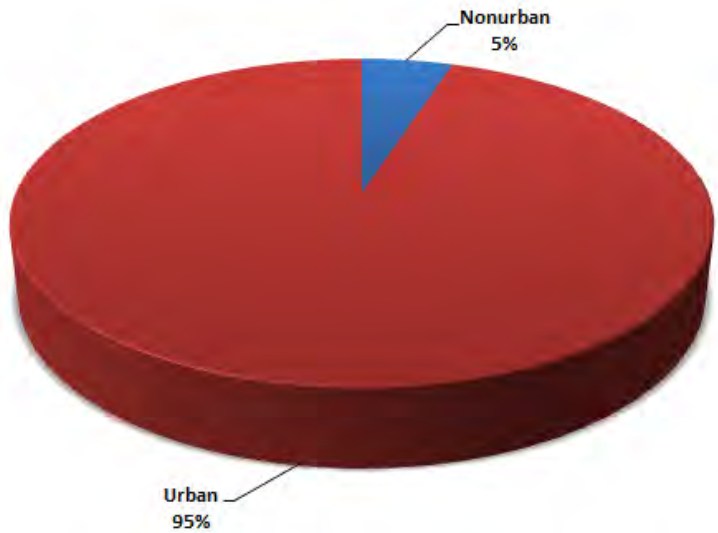

Figure 3–7. Source Allocation for the Impaired Crow Creek Reach.

The **HSPF** model application was also used to locate TSS contributions from basins within the urbanized area, as depicted in Figure 3-8. Figure 3-9 is the source allocation by basin shown in Figure 3-8. Henderson, East Lincolnway, Dry Creek, and Allison Basins are not included in the source allocation because their contributions occur downstream of the impairment. Similarly, the local drainage area in the pie chart only includes that located above the impaired reach endpoint.

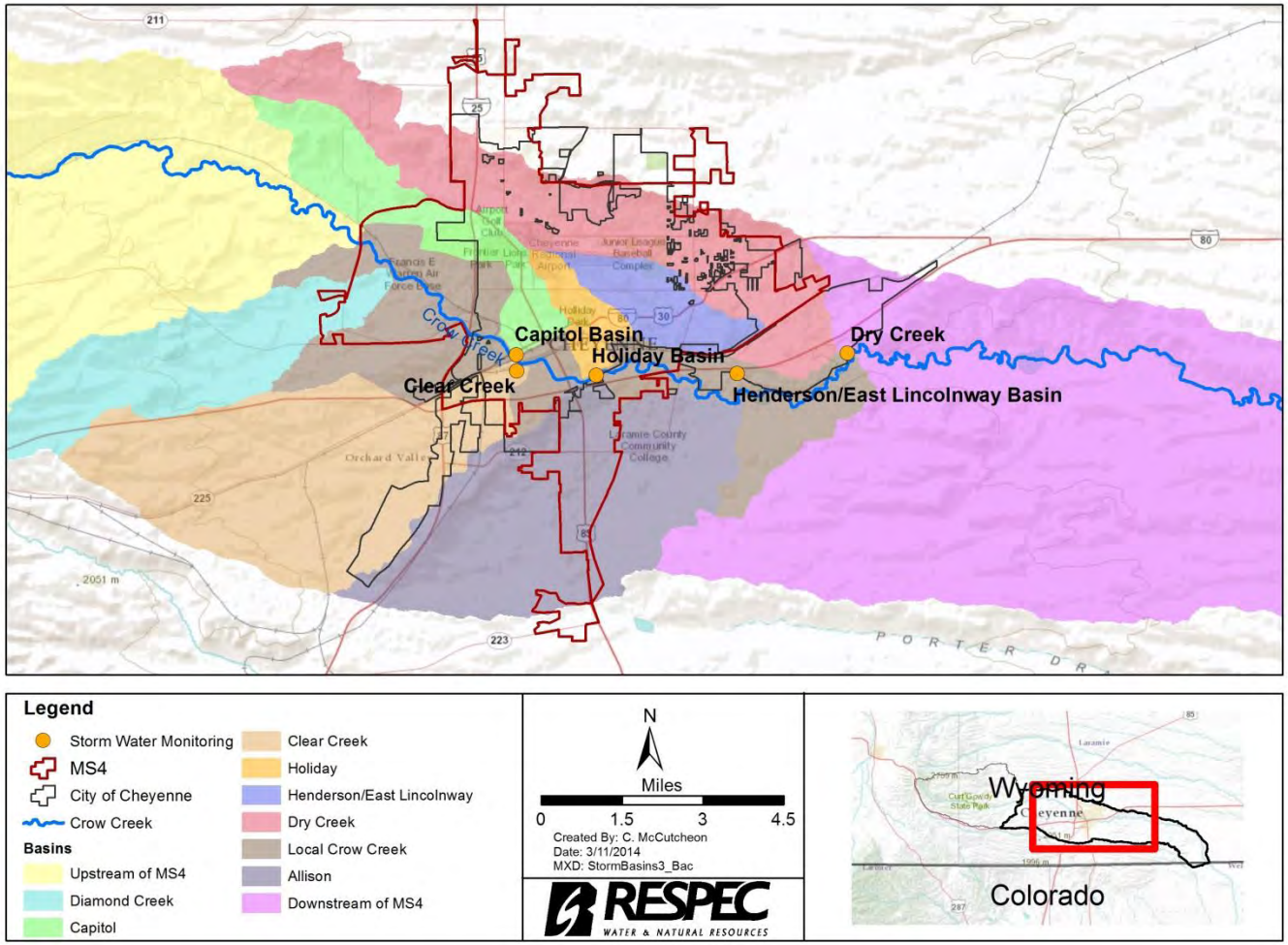

Figure 3–8. Urbanized Area Drainage Basins.

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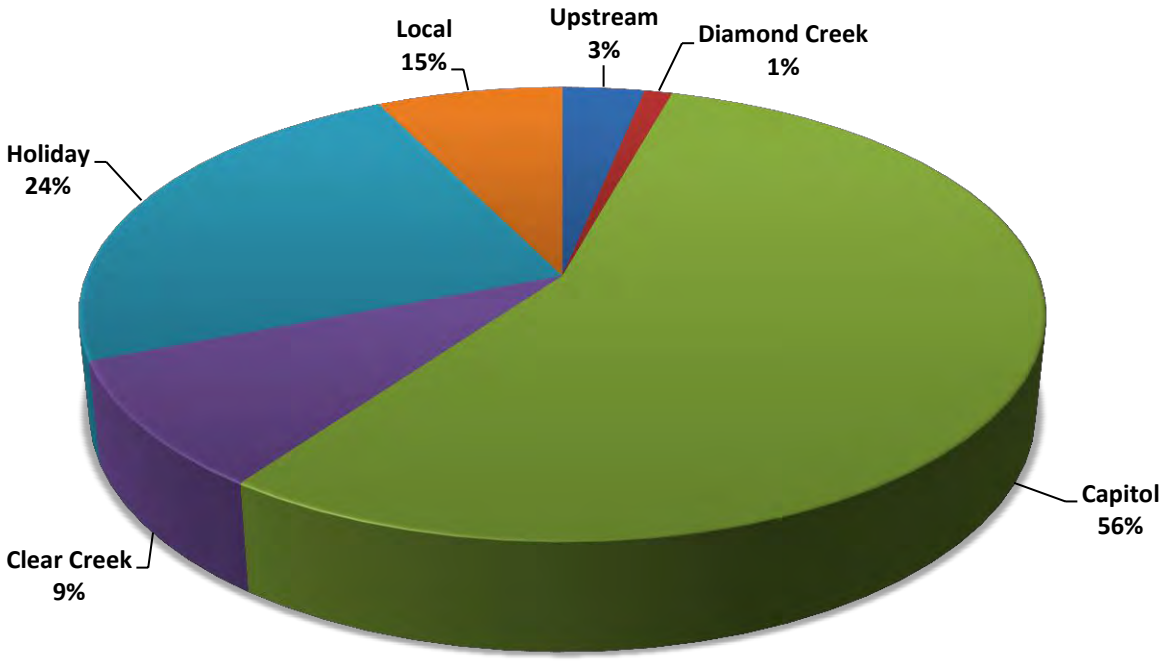

Figure 3–9. Source Allocation by Urban Drainage Basin Within the Crow Creek Project Area.

4.0 TOTAL MAXIMUM DAILY LOAD AND ALLOCATIONS

The TMDL (loading capacity) is the sum of the load allocation (LA), the wasteload allocation (WLA), and the margin of safety (MOS) and is provided in Equation 4-1.

$$\text{TMDL} = \text{LA} + \text{WLA} + \text{MOS}. \tag{4-1}$$

Because sediment is primarily delivered in pulses to Crow Creek during storm events, and the allowable loading that leads to a healthy ecosystem is ultimately determined by the stream's capacity to transport the sediment in adequate quantities with proper bed substrate, the loading capacity was determined by modeling the bed material sediment transport capacity of Crow Creek by using the **HEC-RAS** hydraulic design module **SIAM**.

4.1 HEC-RAS MODEL

A one-reach, steady-flow **HEC-RAS** model was developed from existing **HEC-2** and **HEC-RAS** models of Crow Creek. The **HEC-RAS** modeling was based on the 1988 Crow Creek **HEC-2** modeling by CH2M HILL and was supplemented with 1992, 2003, 2006, and 2009 updates to reflect channel modifications and development in the reach. The original models used for this study were primarily developed to delineate Federal Emergency Management Agency (FEMA) base flood elevations and to assess development impacts for the 100-year (base flood) event. Although the model developed for this project from the original models is not detailed enough to capture habitat-level channel features, it is considered suitable for developing reach-averaged sediment transport capacity estimates.

The model extends from Hereford Reservoir upstream approximately 41,000 feet to I-25 and includes the entire length of Crow Creek within the MS4 area. This study reach was subdivided into six segments, or subreaches, for sediment transport capacity analysis based on the field reconnaissance effort performed to support TMDL development. For the model, manning roughness coefficients and crossing structure data were generated from the existing modeling data and adjusted for internal consistency to match field observations. In addition, sediment transport capacity rating curves were predicted for each of the six subreaches. The discharge range simulated by the **HEC-RAS** model varied from 2.6 cfs to 700 cfs and encompassed the range of flows predicted by the **HSPF** model at the TMDL measurement point (the Morrie Avenue crossing over Crow Creek).

To aid in interpreting and implementing the TMDL, and adhering to guidance provided by the EPA [2007], the TMDL was separated into five flow zones based on peak flows: high (0–10 percent), moist (10–40 percent), midrange (40–60 percent), dry (60–90 percent), and low (90–100 percent). The TMDL peak flow zones were developed from the 15-year, hourly **HSPF** hydrology simulation results for Crow Creek and a threshold lower bound discharge for sediment transport monitoring. The threshold was set to 40 cfs at Morrie Avenue based on a Rouse number analysis performed for the reach (i.e. flows in excess of 40 cfs predicted fully

suspended bed material). The Rouse number was estimated for each sediment size fraction, and results from the Rouse number analysis are provided in Table 4-1. The results of the **HEC-RAS** analysis indicated that, for discharges in excess of 40 cfs, fine sand and finer fractions are transported as suspended bed material load in the water column. If a simulated flow at a given location exceeded the 40 cfs threshold value, then the hourly flows and corresponding sediment transport capacities were recorded for the subsequent 24-hour period. The peak flow value was recorded and the hourly flow volume and corresponding sediment transport capacity were summed over the 24-hour event. This flow-weighted summation captures the hydrologic variability associated with each event. All such 24-hour events were recorded for the 15-year **HSPF** simulation. The event peak discharges were then ranked in increasing order, and the 10-, 40-, 60-, 90- and 100-percentile event peak discharges were determined using a Weibull plotting position. These peak discharges, corresponding to the low, dry, midrange, moist, and high flow zones, are presented in Table 4-2.

4.2 LOADING CAPACITY

Sediment transport capacity rating curves for Crow Creek were developed by using the **HEC-RAS** model. Reach-average hydraulics and corresponding sediment transport capacities were developed for six mainstem subreaches: I-25 to 19th street, 19th Street to Capitol Basin Outfall, Capitol Basin Outfall to Ames Avenue Culverts, Ames Avenue Culverts to 1st Street, 1st Street to Morrie Avenue Outfall, and downstream of Morrie Avenue Outfall. These rating curves covered the range of flows predicted by the **HSPF** model application for its 15-year simulation period (1995–2010). An example of a sediment discharge rating curve at Morrie Avenue is presented in Table 4-3.

These sediment transport capacity rating curves were used to estimate the sediment transport capacity at selected locations along Crow Creek for each 24-hour event predicted by the **HSPF** model application. The sediment transport capacity and flow volume for all events within each flow zone were averaged to determine the representative sediment load for each flow zone. The results for Morrie Avenue, which are presented in Table 4-4, indicated that the reach downstream of the Morrie Avenue Outfall to Crow Creek represents the controlling sediment transport capacity of the stream and is the point at which most major sediment contributions from the urbanized area have been delivered to the stream.

The sediment transport capacity in this reach largely reflects the existing sediment supply, and if sediment supply is reduced to the current reach-average sediment transport capacity, it may not adequately support the preferred habitat values and recovery of Crow Creek's designated uses. Therefore, the TMDL loading capacity target was set 10 percent below the predicted Morrie Avenue subreach sediment transport capacity to encourage flushing of stored sand and fine gravel materials. This sediment reduction will result in coarsening the bed material, as stored sand and fine gravel are entrained and transported out of the study reach, and will result in flushing of the stored sand and fine gravel observed upstream of restrictive channel crossings and throughout the impaired reach. This sediment deficit will also likely cause minor degradation. However, the presence of man-made control points and consolidated

material in the bed, particularly through the urban corridor, will limit the depth of degradation and prevent significant channel destabilization. Consequently, the monitoring program must include a periodic geomorphic and habitat assessment component to identify potential negative habitat and stream stability outcomes that arise from any BMP activity to restrict sediment supply to Crow Creek.

Table 4-1. Rouse Number as a Function of Particle Size for Crow Creek at Morrie Avenue

Flow (cfs)	Rouse Number		
	Diameter (mm)		
	0.125–0.25	0.25–0.5	≥1
	Fall Velocity (feet per second)		
	0.12	0.25	0.45
0.80	1.8	3.8	6.8
2.6	1.6	3.3	5.9
7.4	1.3	2.8	5.0
14	1.4	2.9	5.1
24	1.3	2.7	4.8
34	1.2	2.5	4.5
45	1.2	2.4	4.4
55	1.1	2.4	4.2
69	1.1	2.3	4.1
90	1.1	2.2	4.0
108	1.0	2.2	3.8
128	0.99	2.1	3.7
149	0.96	2.0	3.6
167	0.94	2.0	3.5
186	0.92	1.9	3.5
199	0.91	1.9	3.4
223	0.89	1.9	3.3
244	0.88	1.9	3.3
262	0.87	1.8	3.3
281	0.86	1.8	3.2
300	0.85	1.8	3.2
330	0.83	1.7	3.1
337	0.82	1.7	3.1

Yellow = all-suspended; Orange = mixed bed-suspended load; No Fill = bedload

Table 4-2. Flow Intervals for the Total Maximum Daily Load Calculations

Flow Bin (%)	Maximum Event Discharge (24-Hour Peak Hourly Discharge (cfs)	Number of Days
Low (0–10)	40–47	31
Dry (10–40)	47–86	92
Midrange (40–60)	87–126	60
Moist (60–90)	127–248	92
High (90–100)	249–435	28

Total 24-hour events exceeding 40 cfs peak flow threshold N days = 303 for simulation period.

The controlling reach sediment transport loading capacities and **HSPF**-predicted sediment supply for Crow Creek are presented in Table 4-5, in which the TDML loading capacity targets are highlighted green. The loading capacity may require adjustment, if the results of the sediment monitoring program's geomorphic review, habitat assessment, and channel survey indicate that BMP installation and resulting sediment reduction is causing excessive degradation, instigating channel instability, or causing undesirable habitat modifications in the study reach.

4.3 MARGIN OF SAFETY

An explicit MOS, identified using a duration curve framework, is an unallocated load intended to account for uncertainty (e.g., loads from tributary streams and effectiveness of controls). An explicit MOS was calculated as 10 percent of the allowable load in each flow zone, which leaves part of the available loading capacity unallocated and ensures that allocations will not exceed the load associated with the minimum flow in each zone [U.S. EPA, 2007].

4.4 WASTE LOAD ALLOCATION

The WLA is the sum of the point-source allocations (PSAs) and the MS4 loads within each reach. Multiple point sources, discussed in Section 3.1, are located within the project area. However, because this TMDL is for bedload and the permitted point-source facilities do not discharge course-grained sediment, PSAs were not included for the permitted facilities.

National Pollutant Discharge Elimination System- (NPDES-) regulated stormwater discharges must be addressed by the MS4 portion of the WLA component of this TMDL. The urban source contribution percentage of bed material load to Crow Creek (91 percent), calculated by using the **HSPF** model application, was used to estimate the MS4 portion of the

WLA. The urban source contribution fraction (0.91) was multiplied by the difference between the loading capacity and the MOS. Note that this 91 percent is slightly different from the urban percent discussed in Section 3.3, which outlined the percent of TSS instead of bedload from urban versus nonurban sources. In this case, 91 percent of the available allowable load (after the MOS) was allocated to the WLA, which represents the allowable load from the sum of the MS4 permits and all of the construction, industrial, and mining permits described in Section 3.1.

Table 4-3. Controlling Sediment Transport Rating Curve at Morrie Avenue Bridge (CRC 650)

Discharge (cfs)	Sediment (tons/day)
0.8	0.02
2.6	0.28
7.4	2.44
14	4.28
24	9.76
34	16.4
45	24.3
55	32.2
68	43.1
90	63.1
108	81.8
128	105.0
149	130.8
167	154.7
186	183.2
199	201.4
223	239.9
244	269.2
262	288.9
281	321.7
300	355.6
330	411.4
337	425.3
435	615.4
646	1,082

Table 4-4. Event Average Sediment Transport Capacity and Flow Volume by Flow Bin

24-Hour Event	Event Average Results Morrie Avenue Bridge (CRC650)		
Flow Zone	Hourly Peak Discharge (24-hour event) (cfs)	Average Flow Volume (ac-ft/day)	Event Mean Sediment Discharge (tons/day)
Low	47	74.5	19
Dry	86	94.6	27
Midrange	126	161.7	57
Moist	248	266.7	117
High	435	451.0	254

Table 4-5. Sediment Transport Capacity for Crow Creek Downstream of Morrie Avenue Outfall

24-Hour Event	Event Average Results							
Flow Zone	Peak Discharge (cfs)	Flow Volume (ac-ft/day)	Predicted Sediment Transport Capacity (tons/day, percentage of full capacity)					HSPF-Predicted Sediment Supply (tons/day)
			82%	85%	90%	95%	100%	
Low	47	74.5	15	16	**17**	18	19	15
Dry	86	94.6	22	23	**24**	26	27	41
Midrange	126	161.7	47	49	**52**	54	57	65
Moist	248	266.7	96	100	**106**	112	117	91
High	435	451.0	207	216	**229**	241	254	216
Weighted Sediment Supply Reduction Required			13.6	11.5	**10.2**	8.9	7.6	N/A

N/A = Not Applicable

4.5 LOAD ALLOCATION

The LA represents the load allowed from nonpoint sources, accounts for uncertainty in the loading capacity, and is generally calculated as the loading capacity minus the WLA and the

MOS. The LA in each flow zone was calculated as the difference between the TMDL, the MOS, and the WLA, and, in this case, it represents approximately 9 percent of the allowable loading capacity minus the MOS.

4.6 TOTAL MAXIMUM DAILY LOADS

Table 4-6 presents the TMDL with the current load and the necessary reductions for the impaired reach. Current loads for each flow zone were calculated using the average of the total 24-hour event TSS loads (converted to bed material loads by using the regression equations discussed in Section 3.3) from the **HSPF** model application outputs. A 24-hour event occurs whenever flow at Crow Creek exceeded or equaled the 40 cfs threshold set using the Rouse Number analysis. Sediment transport capacity and sediment supply to Crow Creek is then incremented over the subsequent 24-hour period. Reductions are required in the midrange and dry flow zones. The flow-weighted percent reduction for all estimated flow zones that are required to meet the TMDL is 10 percent. This reduction should help the stream adjust toward the preferred geomorphic conditions without a substantial risk of destabilizing the system and causing channel transformation, excessive bank and bed erosion, and other undesirable geomorphic and habitat impacts.

Table 4-6. Crow Creek Sediment Total Maximum Daily Load

TMDL Component (tons/day)	Flow Zone				
	High	Moist	Midrange	Dry	Low
	> 248 cfs	248–126 cfs	126–86 cfs	86–47 cfs	< 47 cfs
LA	19	9	4	2	1
WLA	187	86	43	20	14
MOS	23	11	5	2	2
TMDL	229	106	52	24	17
Current Load	216	91	65	41	15
Load Reduction	0	0	13	17	0
Load Reduction	0%	0%	20%	41%	0%
Overall Reduction Required = 10%					

5.0 SEASONALITY

Monthly precipitation, stream flows, and TSS concentrations in Crow Creek displayed seasonal variation. Precipitation from the Cheyenne airport (1990 through 2011) was used to calculate minimum, average, and maximum monthly precipitation, as illustrated in Figure 5-1. The figure illustrates that average monthly precipitation is generally the highest in May, June, and July (2.3 inches).

A boxplot of flow data at CRC400 is depicted in Figure 5-2. Flows were typically highest during spring and summer months and lowest during fall months. The maximum average flows occurred in May, and the minimum average flows occurred in September.

Available TSS data for mainstem project sites were used to create the monthly boxplots illustrated in Figure 5-3 and to calculate the monthly median sediment concentrations shown in Figure 5-4. The boxplots show that the higher average and median sediment concentrations occurred from May through August and the highest concentration occurred in July (143.9 mg/L). Additionally, monthly median TSS concentrations by site show that stormwater sites were more seasonal than mainstem sites. Because higher flows and TSS concentrations occur during the spring and summer months, TSS loads are also assumed to be highest during the spring and summer months. Similarly, the seasonal bedload is caused by flow seasonality, because higher flows increase the transport capacity.

Short-duration, high-intensity rainstorms are common during the summer months. These localized summer storms can cause significant runoff and increased TSS concentrations for a relatively short period of time while only slightly increasing stream flows. However, by using the flow zone approach to develop the TMDL allocations, seasonal variability in flow and sediment loads are taken into account, because stream flow and sediment delivery to the stream are related to seasonal changes in precipitation. Summer is also a critical time period because of seasonal differences in precipitation patterns and land uses. Typically, livestock are allowed to graze along the streams during the summer months and this increases erosion potential. Construction is also more likely to occur during the spring and summer months because of Wyoming's cold winter temperatures. High-intensity rainstorm events are common during the summer and, combined with the peak in sediment sources, produce a significant amount of sediment load because of higher flows and runoff from rangeland, cropland, and construction zones.

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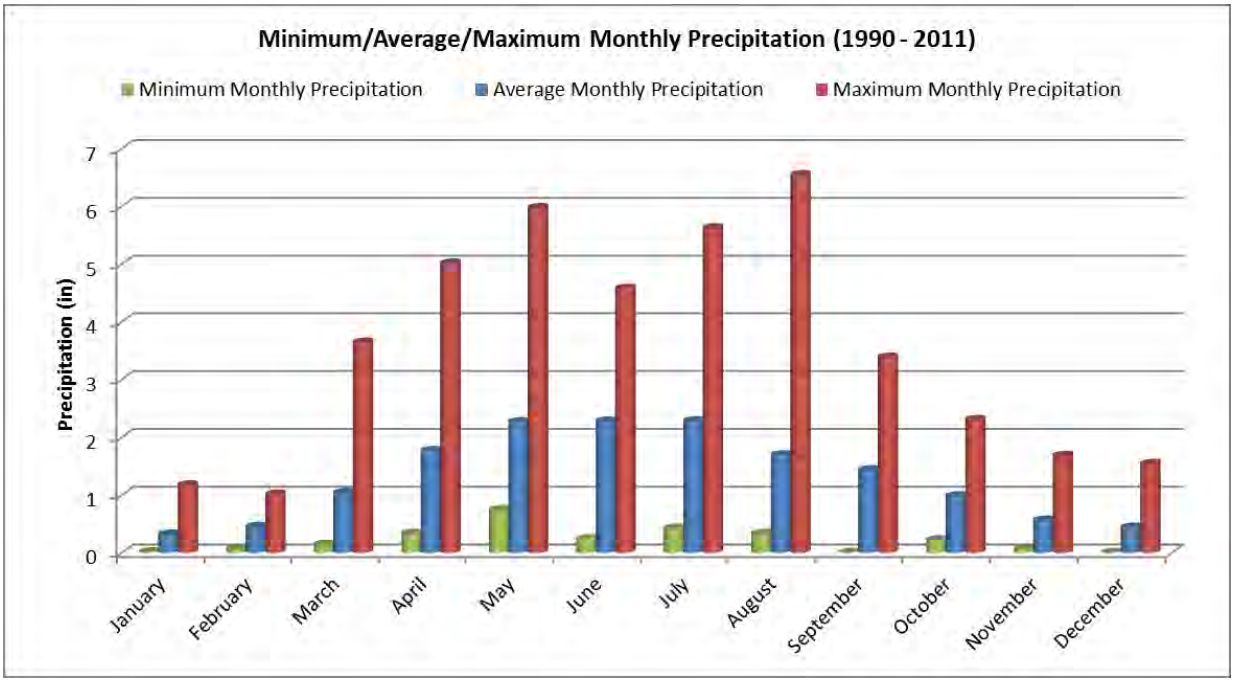

Figure 5–1. Minimum, Maximum, and Average Monthly Precipitation at the Cheyenne, Wyoming, Airport.

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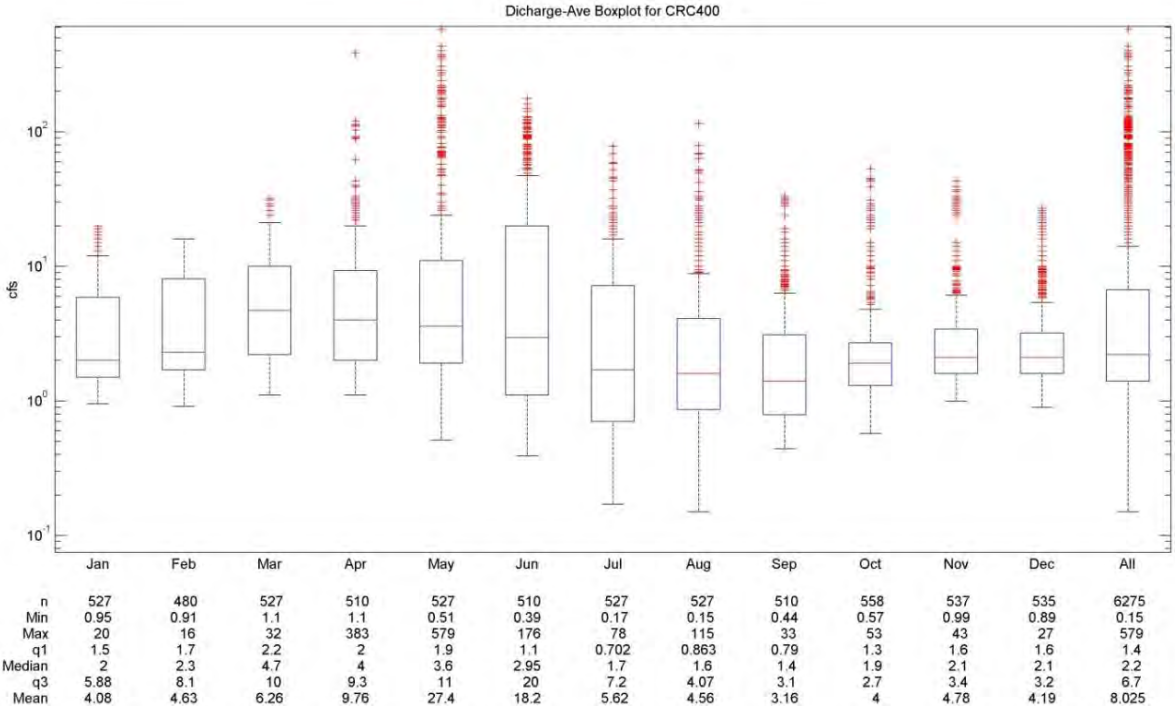

Figure 5–2. Monthly Boxplot of Flow at CRC400.

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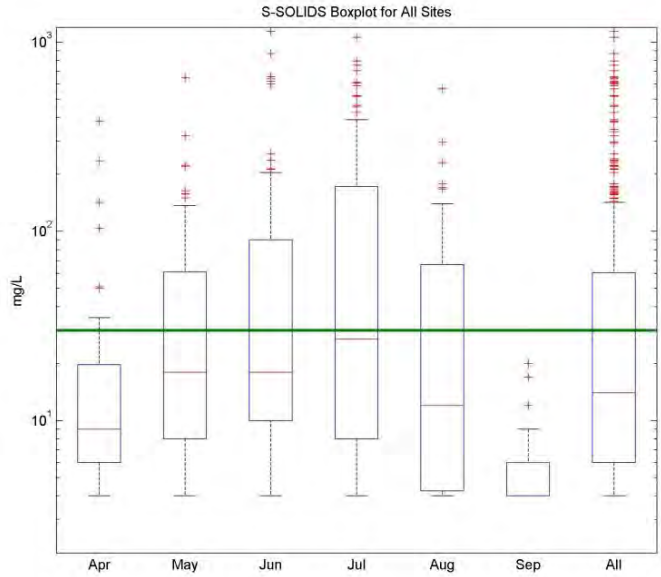

	Apr	May	Jun	Jul	Aug	Sep	All
n	51	128	70	90	71	39	449
Min	4	4	4	4	4	4	4
Max	383	647	1140	1060	566	20	1140
q1	6	8	10	8	4.25	4	6
Median	9	18	18	27	12	6	14
q3	19.8	61	90	172	66.8	6	60.5
Mean	28.6	45.3	115.4	143.9	50.3	6.51	71.53

Figure 5–3. Monthly Boxplots of Sediment Concentrations.

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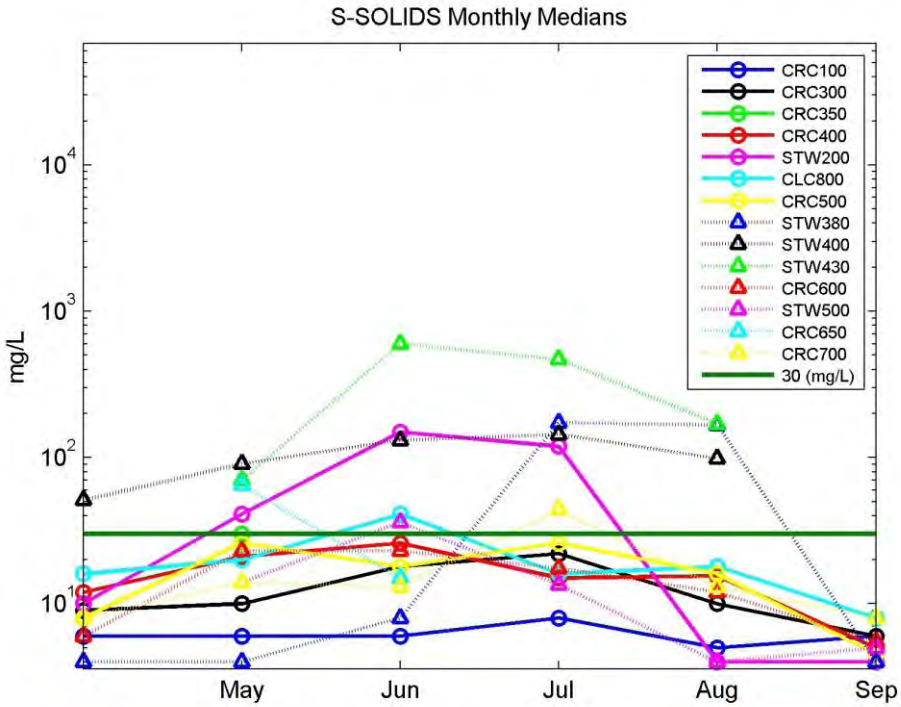

Figure 5–4. Monthly Median Sediment Concentrations.

6.0 PUBLIC PARTICIPATION

Efforts to facilitate public education, review, and comments with developing the Crow Creek sediment TMDL included presentations on the findings of the assessment to local groups in the watershed, a feature photograph in a local media publication, and a 30-day public notice period for public review and comment on the draft TMDL document. All input, comments, responses, and suggestions from public meetings and the public notice period have been addressed or considered in developing the TMDL. Throughout the project, monthly meetings were held with the WDEQ, the city of Cheyenne, the LCCD, and the TMDL consultants. The public notice was published in the ____ and the ____. The document was also made available through the WDEQ's website. Table 6-1 lists specific announcements and events. A photograph of a sampling site and field crew and a brief project summary was published on the front page of the *Wyoming Tribune Eagle* on August 12, 2010.

Table 6-1. Crow Creek Public Outreach Announcements and Events

Date	Outreach	Description
08/19/2009	Crow Creek Watershed Meeting/Tour	Transition from watershed planning to TMDL development
09/08/2009	WDEQ press release on TMDLs	Review and provide comments to Mr. Eric Hargett, WDEQ
10/20/2009	Wyoming Game and Fish projects for Crow Creek	Coordinate with Wyoming Game and Fish for delaying fish projects until after TMDL
02/2010	Newspaper insert on water quality	*Wyoming Tribune Eagle* and *Pine Bluffs Post*
02/2010	*Crow Creek Connection* (Winter 2010)	TMDL and water-quality update to Crow Creek Watershed Committee
04/29/2010	Posted open house announcement on website	Announcement provided
05/11/2010	Newspaper insert on water quality	Delivered supply of extra inserts to Laramie County Planning Office
06/15/2010	Public meeting	Direct mailing to landowners on or near Crow Creek; Laramie County Library
08/12/2010	*Wyoming Tribune Eagle* Article	A photograph of a sampling site and field crew and a brief project description was published on the front page
09/21/2010	Crow Creek Watershed Meeting/Tour	Update on TMDL and projects with watershed committee members
01/18/2011	Stakeholder meeting	Meeting held at Laramie County Library
02/2011	Newspaper insert on water quality	*Wyoming Tribune Eagle* and *Pine Bluffs Post*
	TMDL public notice	TMDL was public noticed in the _____

7.0 MONITORING STRATEGY

During and after implementing management practices, monitoring is necessary to ensure the TMDLs are attained. Geomorphic and habitat monitoring are recommended at a maximum 5-year interval. The recommended geomorphic monitoring includes a repeat cross-section survey, a channel profile survey, bulk bed material sampling, and a geomorphic review to support assessment of geomorphic responses to BMP-induced sediment supply modifications for remediating Crow Creek. An initial cross section and channel profile survey at two subreaches (Westland Road to 19th Avenue and Morrie Avenue Outfall to Refinery Road) to provide a reasonable basis for comparing the current condition and future conditions once the BMPs are implemented is strongly recommended. Any survey should be georeferenced to fixed horizontal and vertical control. A habitat survey is also recommended to document the current (2013) habitat conditions on Crow Creek.

In addition to the geomorphic and habitat monitoring, automated, suspended sediment monitoring is recommended at two locations on Crow Creek. Because an accurate, long-term, direct bedload measurement program is not practicable for a flashy, thunderstorm event-driven, urban stream such as Crow Creek, automated sampling is recommended to measure the suspended fraction of the bed sediment load for all events (24-hour period) when peak discharge exceeds the 40 cfs threshold value. Two automated, suspended-sediment monitors are recommended to be placed on Crow Creek: one at an upstream location near Westland Road and the other at Morrie Avenue. It is also recommended that these sediment samplers be placed to capture as much suspended sediment as possible at each location. Lastly installing an automated sampler with multiple sample bottles that are capable of capturing hourly TSS samples over a 24-hour period with concurrent discharge measurements at the TMDL monitoring locations is recommended.

The WDEQ will use this monitoring strategy to reevaluate the TMDL as the implementation proceeds. This will occur at a minimum of every 5 years as outlined in the WDEQ TMDL Work Plan [Wyoming Department of Environmental Quality, 2008b]. The WDEQ will notify the EPA, and a new public review will be made available if any changes or adjustments are needed after the reevaluation.

8.0 REASONABLE ASSURANCE

A variety of BMPs could be considered in developing a water-quality management implementation plan in the project area. While several types of control measures are available for reducing sediment supply, the practical control measures listed and discussed in this chapter are recommended to address the identified sources in the Crow Creek project area. Based on water-quality monitoring and **HSPF** model results, implementing the recommended control measures in Crow Creek are expected to reduce sediment supply by up to 19 percent. Further details on BMPs to be implemented in the Crow Creek project area that incorporate the EPA's 9 Key Elements for Section 319 Funding are included in the *Crow Creek Implementation Plan* [Krajewski, 2013].

The two management scenarios that were simulated for the sediment-impaired reach by using the **HSPF** model included incorporating the following:

- 50 percent sediment supply reduction upstream of CRC100 from agricultural BMPs
- 25 percent sediment supply reductions of on 100 percent of the urban area.

The model results show that implementing agricultural BMPs upstream of CRC100 would result in a 0.2 percent total load reduction. Simulating sediment supply reductions of 25 percent on 100 percent of the urban area resulted in a total load reduction of 18.8 percent. The large reduction indicates that sediment supply removal in runoff from the urbanized area would have a large impact on sediment supply.

Thus, there is reasonable assurance that implementing both scenarios would help achieve optimum sediment supply reduction in Crow Creek.

The model results adequately represent BMP reductions and that the goals of this TMDL can be met with (1) proper planning between state and local regulatory agencies, organizations, and stakeholders; (2) BMP implementation; and (3) access to adequate financial resources. The summary of BMP modeling scenarios conducted during this TDML assessment provides reasonable assurance that the impaired section of Crow Creek will attain WSII and WY RIVPACS scores similar to scores between the Happy Jack Road site and the Deming Avenue site. Because both BMP scenarios will decrease sediment supply for the impaired segment by up to 19 percent, and because the overall reduction required by the TMDL is 11 percent, the TMDL can be reasonably implemented. The sediment supply can decrease to an amount lower than its transport capacity (similar to the sediment supply targets), which provides further reasonable assurance that the aquatic life use condition will be met with the reductions specified by this TMDL.

Given the potential BMP reductions practicable for Crow Creek, a BMP strategy can be implemented that will reduce bed sediment material supply to target levels. These targets have

been set to generate a minor sediment reduction in the impaired reach. Combined with replacement of restrictive crossings over time, implementing BMPs will actively flush existing, excess sediment deposits from the impaired reach. This tendency can be observed in the Morrie Avenue subreach, because the sediment stored upstream of the 1st Street culverts and Morrie Avenue culverts has started to mobilize; cobble bars are exposed, and the channel is coarsening and incising to form a single-thread channel subsequent to replacing culverts with bridge crossings in these locations. This minor sediment supply deficit relative to the existing sediment transport capacity in the sediment transport critical reach will, over moderate engineering time scales, tend to preferentially flush sand and fine gravel downstream, coarsen the bed substrate, reduce bed mobility, and flush the sediment stored upstream of restrictive crossings. A minor sediment deficit will also encourage the braided subreaches of the stream to consolidate into a single-threaded, meandering channel where the channel is not overconstrained in its man-made floodway.

The impaired reach is likely to experience limited degradation and will tend to coarsen to some degree because of anthropogenic bed level control (culverts, armored pipeline crossings, and diversion structures), caliche deposits, and bedrock outcrops that partially constrain channel vertical mobility. Although aquatic life conditions similar to those at the Happy Jack Site are the overall goal, maintaining conditions similar to the reach between Happy Jack Road and Deming Drive is sufficient in leading to attainment of the beneficial use that supports a benthic macroinvertebrate community very similar to that at Happy Jack Road. Crow Creek is expected to readily coarsen from a coarse, sand-to-fine gravel bed stream to a fine-to-medium gravel bed stream with some subreaches developing lag cobble surface layers over reasonable engineering time frames.

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APPENDIX A

TOTAL SUSPENDED SOLIDS QUALITY ASSURANCE REPORTING

APPENDIX A
TOTAL SUSPENDED SOLIDS
QUALITY ASSURANCE REPORTING

Quality assurance procedures for field sampling were followed for all of the data collection for this project. The basic handling procedures were followed and listed below:

- Sample bottles were rinsed with the stream water to be sampled.
- Containers were appropriate to parameters sampled, and the required cleaning procedures were followed.
- A regular schedule of field instrumentation calibration was followed to ensure that the instruments were working properly and within the range of manufacturer-specified acceptability. Instruments were calibrated according to manufacturer instructions before field use and periodically thereafter, and calibrations were recorded on log sheets.
- All instruments were examined for maintenance recommendations and checked for proper operation, and the required maintenance was performed immediately to ensure acceptable operation before the next use.

QA/QC sample sets were collected as part of the sediment monitoring effort and consisted of field replicates and blanks. Field replicate samples were independent samples that represented the parameters of interest for which a second sample was collected in the same manner, with the same equipment, and as close in time and space to the previous sample as possible. Marks were not used that would indicate that the sample is anything other than a regular sample from the station identified on the label. The location and date of the replicate sample and the regular, or routine, sample were recorded. Relative percent difference (RPD) was calculated for each replicate sample pair as follows:

$$\mathrm{RPD} = \left(\left|S - R\right|\right) \Big/ \left(\left(S + R\right)/2\right) \times 100 \qquad \text{(A-1)}$$

where S is the sample and R is the replicate. For replicate sediment samples, the average RPD was 16 percent, the median was 9 percent, the minimum was 0 percent, and the maximum was 86 percent. At low concentrations, RPD is not an accurate method for comparing replicates, and it is at these low concentrations where the highest RPDs occur. Because sediment is typically more variable in nature, it should have an RPD of less than 40 percent. Less variable parameters are expected to have an RPD of less than 20 percent. Small differences between replicate and routine samples may exist as a result of contaminated sample bottles, laboratory error, inherent variability of laboratory method, or stream variability.

Field blanks were collected during regular sampling activities at random sites during the base flow sample collection and storm events. Field blanks were used to determine if the

procedures used for equipment decontamination and sample collection, storage, and transport were sufficient to ensure the integrity of the samples. Field blanks were collected, stored, and shipped with other samples. All but one of the field blanks (n = 52) collected for this project did not detect sediment. The one blank with sediment occurred on July 12, 2010, (when four field blanks were taken).

APPENDIX B

GEOMORPHIC ASSESSMENT

CROW CREEK PRELIMINARY GEOMORPHIC ASSESSMENT

The following is a preliminary geomorphic assessment of Crow Creek, which flows through the City of Cheyenne, Wyoming. This geomorphic assessment is based on reconnaissance of the creek, sediment sampling conducted at a number of sites along the creek, an examination of historic flow records and anecdotal accounts of floods on the creek, surveyor's notes from General Land Office (GLO) surveys conducted in 1870, and a comparison of historic maps and aerial photography. The 2009 Wyoming DEQ water quality report was also reviewed. The following preliminary assessment will present data and information collected as part of this effort as well as an interpretation of the data and information and some general conclusions.

Project Reach

The project reach of Crow Creek (**Figure 1**) examined as part of this assessment extends from the Happy Jack Road crossing near the intersection with Missile Drive at the southeast corner of F.E. Warren Air Force Base downstream to the Crow Creek Wastewater Treatment Facility (WWTF). Because of access restrictions, however, the geomorphic field reconnaissance only examined the reach downstream to the Haystack farm road bridge southeast of the oil refinery.

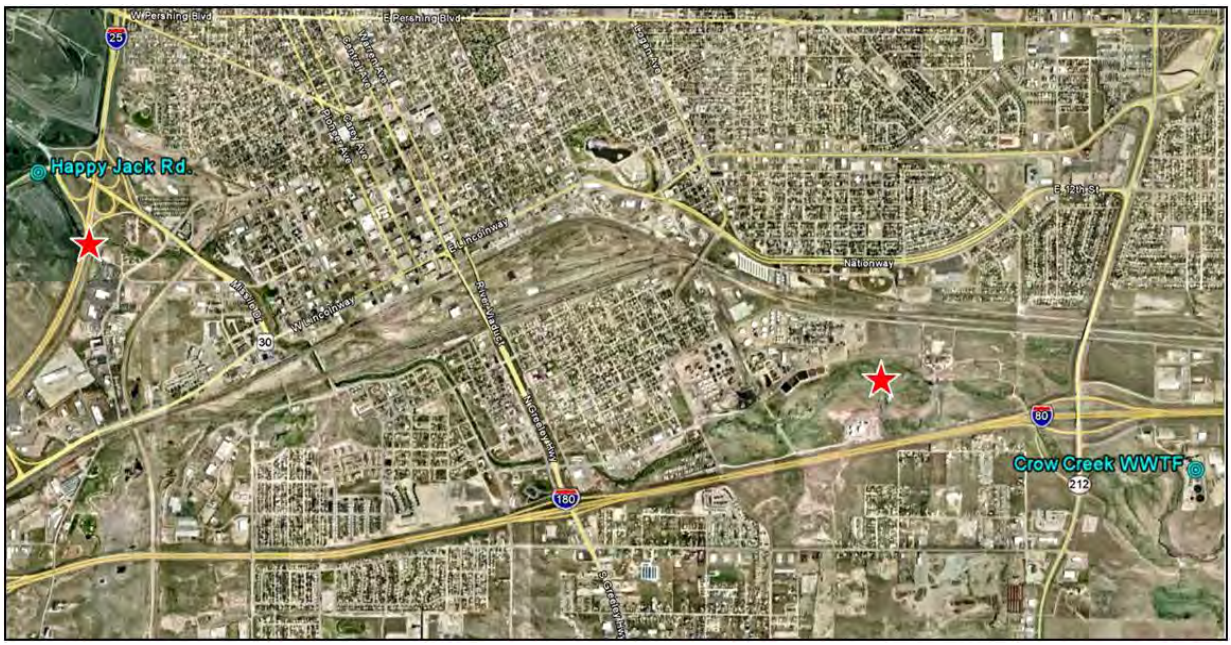

Figure 1. Project reach of Crow Creek in Cheyenne, Wyoming. The reach examined during the geomorphic field reconnaissance is marked by the red stars.

Historic Channel Position and Planform Changes

An examination of the historical morphology and changes that have taken place on Crow Creek is necessary for understanding and evaluating the current conditions on Crow Creek. Historic maps and aerial photos, GLO survey notes, and other historic records were examined to determine what Crow Creek might have looked like more than a century ago and how it has changed historically.

The surveyor's notes and maps of the GLO survey conducted in 1870 were examined and the planform of the creek from the survey maps was overlain and compared with current and previous courses of the creek. **Figure 2** shows the GLO maps and the width of the creek as described by the surveyor at location where he crossed the creed along section lines. As seen in the figure, the channel widths ranged from 30 links (20 feet) near the upstream end of the reach (near the intersection of Ames Avenue and West Lincolnway) to 150-200 links (100-132 feet) at the downstream end of the reach (near the Crow Creek WWTF east of S. College Drive). Although the GLO maps show the planform and position of the creek in 1870, the position and planform as drawn between the section lines may not accurately reflect the real channel position at that time since the surveyors were not surveying the location of the channel. However, the description and channel position at those locations where the creek crosses a section line can be considered relatively accurate.

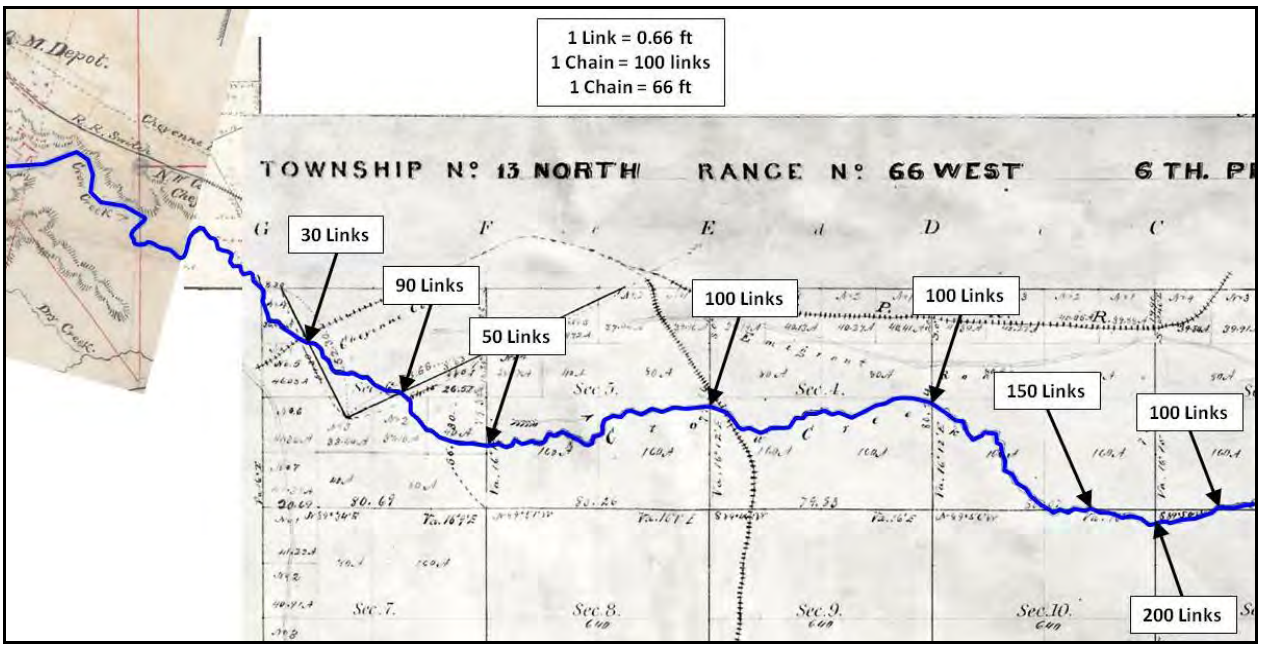

Figure 2. General Land Office maps of the 1870 survey in the vicinity of Cheyenne, Wyoming. Widths (in links) of Crow Creek as noted by the surveyors at that time are shown.

The surveyor described the creek in this reach as being dry over its entire length at the time of the survey, which was conducted in July and August, 1870. He describes the creek as a "wide, small stream running here" at one location where he notes that the creek is 200 links wide. Therefore, this comment might be interpreted to mean that the channel was very wide, but quite shallow, which is common for dry washes on the high plains of the west. In addition, he also described the creek as being "washed," "very badly washed," and "considerably washed" in places. He also notes that there are a number of settlers living along the creek and that, in addition to the natural grasses growing along the creek, the settlers are cutting and curing hay along the creek. **Figure 3** is a picture of a high plains stream showing what the Crow Creek channel might have looked like in 1870 or before settlement of the area based, in part, on observations noted by surveyors conducting the BLM GLO Plats from 1870.

Figure 3. Typical high plains channel showing what Crow Creek may have looked like prior to European settlement of the Cheyenne area in the 1800's.

A USGS topographic quadrangle map of the area around Cheyenne compiled in 1911 was also examined. A portion of the map is provided as **Figure 4** and shows the position and planform of the study reach of Crow Creek at that time. As can be seen in this map, the channel is much more sinuous as compared to the channel shown on the 1870 GLO map.

Finally, the position and planform of the creek from 1870 and 1911 was overlain on the current 1994 USGS topographic quadrangle map of the area and was compared with the current creek planform and position. This comparison is provided in **Figure 5**, which also shows that the western half of the project reach has been relocated and channelized over time. The current alignment, except near the Interstate 25 crossing, was established by 1947 as indicated in an aerial photo taken at that time. As seen in the inset picture in Figure 4, the channel in the area of I-25 was relocated to the south between 1947 and 1960 (based on 1947 and 1960 aerial photos) as part of the construction of I-25 and the interchange at Missile Drive/Happy Jack Road. In addition, the creek was relocated to the north between 1911 and 1947 starting from just downstream of Ames Avenue to about the W. 7th Street bridge as seen in Figure 5 and appears to have been channelized from there downstream to the location of the Morrie Avenue bridge.

Figure 4. A portion of a 1911 USGS topographic quadrangle map showing Crow Creek.

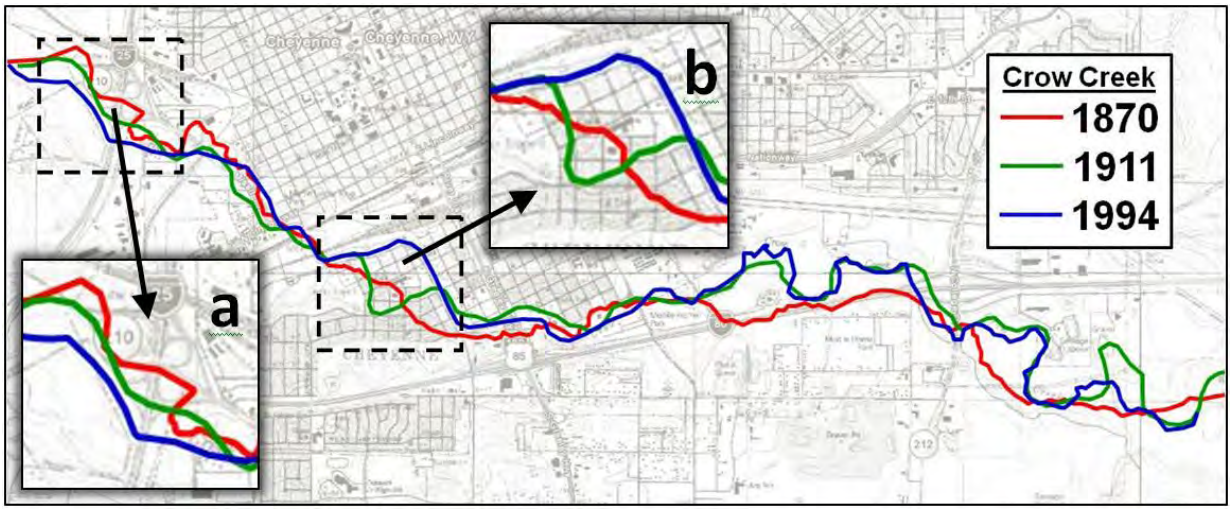

Figure 5. A portion of a 1994 USGS topographic quadrangle map showing the area around Cheyenne, Wyoming, and the position of Crow Creek in 1870, 1911, and 1994. Inset boxes show the re-routing of the channel in the area of (a) the intersection of Missile Dr. and I-25 and (b) between Ames Avenue and W. 7th Street.

Historical Floods

The historic record and anecdotal accounts of floods on Crow Creek were also briefly examined. No gage was present and, therefore, no continuous records are available of flows on Crow Creek within the City until 1993. Only anecdotal accounts are available for flood flows on Crow Creek. The first recorded major flood occurred in May 1904. The discharge was estimated by the State Engineer at the time to “vary from 7,000 to 10,000 cfs for several hours” (Murphy et al. 1905). Mr. A.J. Parshall, a resident hydrographer at the time, described the flood as follows:

About 9 p. m. on May 20 the residents along Crow Creek were suddenly confronted by a wall of water several feet high extending across the valley, varying in width from one-fourth to one-third of a mile, and moving with great rapidity. The resulting damage was the loss of the lives of two children and the destruction of a considerable amount of property, viz, of railway and highway bridges, embankments, public works, and residences. The first alarm at Cheyenne was sounded from the city pump house, a substantial stone structure located near the creek in West Cheyenne, its floor being about 7 feet above the bed of the stream and about 120 feet distant from it. At 9 p. m. May 20 the engineer and family living in the house were warned of some unusual occurrence by a roaring noise, and opening the door were almost simultaneously struck by a wave estimated to have been 3 feet high. The water continued to rise for about three-fourths of an hour, when it reached its greatest height, 5.5 feet above the floor of the building and 12.5 feet above the bed of the creek. Here the width of the bottom covered with water was nearly one-fourth of a mile. After 10 o'clock the water gradually subsided, and at daylight the following morning only a swollen stream with slimy, wreck-strewn banks was to be seen.

Other floods continued to plague the City in the early part of the 20th century until water storage and flood detention reservoirs were constructed within the watershed.

As indicated by the City Engineering Services Department's online flood information documentation, "Flooding in Cheyenne is typically caused by heavy thunderstorm activity which can occur from late spring through early fall. The most deadly of this type of thunderstorm was evidenced on August 1, 1985. This storm event resulted in a 24-hour record rainfall, 12 deaths and $65 million in property damage with significant flooding along Dry Creek and Crow Creek." The record breaking storm produced 7 inches of precipitation in the City's downtown area between 6:20 p.m. and 9:45 p.m. Flooding occurred throughout the City. The majority of the problems associated with this flood on Crow Creek occurred downstream of the I-180 crossing where Lower Capitol Basin stormwater was conveyed once it overtopped the UPRR Yard.

The current project reach USGS gage, which is located at the 19th Street bridge (Martin Luther King Park), provides a continuous record only back to October 1993. Instantaneous peak flows for the last 16 years have not exceeded 800 cfs. The 4 largest recorded peak flows are 769 cfs in 1997, 687 in 1999, 456 cfs in 2008, and 290 cfs in 2010. The peak flows in the remaining years did not exceed 150 cfs.

Geomorphic Field Reconnaissance

The geomorphic field reconnaissance consisted of 2 field site visits. The first field site visit was conducted by the Ayres Senior Geomorphologist, Mr. Bill Spitz, and the Ayres Project Engineer, Mr. Will deRosset, on July 21-22, 2010. During that time, Mr. Spitz and Mr. deRosset walked the creek and collected detailed information on the geomorphic, hydraulic, and sediment characteristics of the creek from just upstream of the I-25 crossing to the reach on the south side of the refinery. Only spot observations were made of the creek downstream of the refinery. Field observations by both Mr. Spitz and Mr. deRosset were documented in field books through the use of field notes and sketches. Field conditions were also documented with ground photos obtained with digital cameras. A Trimble GeoXT handheld sub-meter GPS was used to record the geographic locations of specific features as well as the ground photo locations. Mean daily discharges at the 19th Street gage (USGS Gage 06755960) for July 21st and 22nd were 5.7 cfs and 6.4 cfs, respectively.

The second field site visit was conducted by Mr. Spitz and Mr. deRosset on August 19, 2010, to collect bed and bank material samples along the creek. Sample site characteristics were documented and the sample locations were georeferenced using a handheld GPS. All samples were bagged and transported to a lab for sieving and grain size analysis. The reason the samples weren't collected during the first field reconnaissance trip was because flows during the first trip were sufficiently high to preclude safely and accurately obtaining the samples. In contrast, the mean daily discharge at the 19th Street gage (USGS Gage 06755960) for 19 August 2010 was 1.7 cfs.

In general, the creek over most of the reach is represented by a small inset rectangular channel meandering within a relatively narrow, man-made trapezoidal floodway as shown in **Figure 6**. The channel generally ranges in size from 8-20 feet wide and 2-4 feet deep. The inset floodplain, which is fairly continuous, consists of recently deposited sediments, man-made fill material, and/or in-situ ancient alluvial deposits exposed during mechanical excavation. Depending on the location, the channel bed and bank sediments can range from fine sand and silt to cobbles and small boulders.

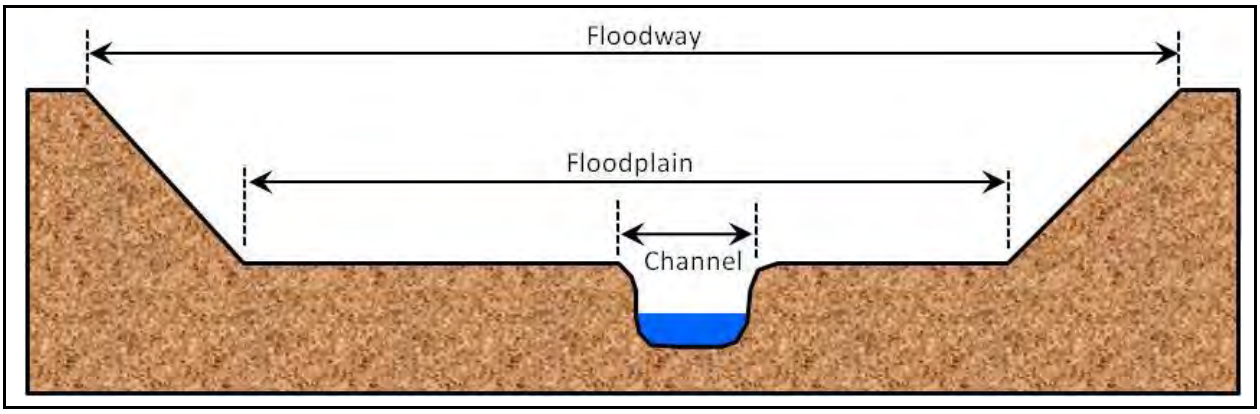

Figure 6. Typical cross section of the Crow Creek floodway, inset floodplain, and inset channel.

The following discussion of channel characteristics and existing conditions on Crow Creek noted during the field reconnaissance is divided up into segments defined by bridge crossings. The defined left and right banks are based on viewing the channel in the downstream direction.

Happy Jack Road Bridge to I-25 Bridges

This segment is a straight, man-made reach consisting of floodway with an inset, slightly meandering channel with an inset floodplain. The banks of the inset channel are currently about 3.5-4 feet high and the channel width varies from 8 to 20 feet with an average width of about 12-15 feet. The inset floodplain is about 30-40 feet wide and the top width of the floodway is approximately 45-50 feet wide.

The inset floodplain is covered with young willows and grasses. The floodplain soils consist of a surface layer of organic rich silt and sand overlying silty, sandy, gravels. A bulk sample of the subsurface floodplain sediments was collected and analyzed for its grain size distribution. The median grain size (D50) of the material is about 1.1 mm. The gravel is sub-angular to subrounded and appears to be alluvium derived from rocks of granitic composition. The bed sediment, where present, is also composed of sand and gravel.

In most places, the inset channel banks, although near vertical, are generally stable. An examination of aerial imagery from 1994 and 2010 indicates that the inset channel position has not changed significantly during that period. However, the channel width during that period does appear to have increased, suggesting that the channel has incised and widened. Caliche (also known as hardpan) and caliche cemented fine grained sediments crop out extensively in the bed and along the lower part of the right bank of the channel throughout this segment. In places, shallow groundwater seepage and spring flow occurs at the contact between the overlying colluvium and the caliche. Along with the apparent widening identified in the comparison of the 1994 and 2010 aerial photography, the presence of bedrock outcrops and the geometry of the channel and banks suggest that this reach has degraded over time.

The conditions at the I-25 bridges also suggest that the upstream channel has incised and widened over time. First, there is concrete bank paving along the right bank just upstream of the bridge that appears to have been emplaced for bank protection, but is currently separated from the inset channel by a fairly wide section of inset floodplain. Large pieces of concrete rubble are present along the base of the concrete paving suggesting that the paving does not extend to any significant depth below the top of the floodplain and, therefore, was probably emplaced to protect the pavement toe from being undermined.

Rock riprap in the channel bed just upstream of the I-25 bridges is currently providing about 2 feet of grade control. The rock spans the entire inset channel width.

Second, there are stains on all of the I-25 bridge piers that are at the same elevation as each other and as the upstream floodplain (**Figure 7**). This would suggest that when the I-25 bridges were constructed in 1957, the ground under the bridges in which the piers were constructed was at the same elevation as the upstream floodplain. It is possible that the channel bed was at or close to the same elevation as the upstream floodplain prior to the construction of the I-25 bridges and that the channel in this reach degraded to its current level following the construction of the bridges. Ayres has requested a copy of the 1957 construction plan set from the WYDOT to verify the degree of degradation that has taken place since the bridges were built.

Figure 7. View from left bank showing old ground line stains (red arrows) on I-25 bridge piers.

The cause of the degradation is unknown but may be in response to either the replacement of the bridge at the I-25 crossing and/or the re-routing of the channel at this location in the early part of the 20th century.
In addition to the exposure of the I-25 bridge piers due to long-term channel degradation, the left bank footing of the abutment on the northbound bridge spill-through abutment is currently being undermined by localized scour (**Figure 8**). This will ultimately lead to failure of or severe damage to the abutment slope paving if left untreated.

Figure 8. View of scour and undermining of the left bank concrete spill-through abutment footing of the northbound I-25 bridge.

Although the channel in the vicinity of the I-25 bridges is generally undergoing long-term degradation, sand (predominately), gravel, and small cobbles is still being deposited in bars under the bridge. Because of the lack of vegetation under the bridges, flow becomes unconfined and is able to spread out and deposit sediment under the bridge. Downstream of the bridges, flow becomes reconsolidated into a well-defined channel.

<u>I-25 Bridges to Westland Road / W. 24th St. Bridge</u>

This segment is similar to the segment upstream of I-25 with the inset channel just as entrenched as the channel upstream of I-25. However, the channel depth decreases in the downstream direction. Outcrops of caliche or caliche cemented sediments in the bed are only evident in a few places in the upper part of this segment and are non-existent in the banks. The inset channel banks contain primarily silt to cobble size sediments. Over much of the reach the inset channel averages about 10-15 feet wide and about 2.5-3 feet deep.

The floodway of the creek in this segment is somewhat narrower than the floodway upstream of I-25 and the banks of the floodway are composed of colluvium that consists of sediment ranging from silt to cobble sizes. The floodway banks are mostly grassed and stable, but where they are only partially grassed, they are eroding due to slopewash.

Where outcrops of bedrock occur, the channel bed is slightly perched and, therefore, the channel is not as deep at those locations. At one site about 260 feet downstream of I-25, a bedrock outcrop in the channel has resulted in a shallow split flow around a 180-ft long cobble bar that has a bedrock core. This split flow bar was also present in the 1994 aerial photos. The upstream end of the bar and outcrop is marked by a tributary confluence on the right bank. This tributary parallels I-25 for some distance to the south and then passes under the highway and drains the area around Little America. Current conditions indicate that the tributary carries little sediment and what sediment it does transport is likely a minor amount of roadside sediments from I-25 and other roads and potentially from parking lots that drain into the channel. It is believed that the tributary is not a significant source of sediment because the upstream channel is heavily grassed with no apparent exposed sand and gravel deposits, the delta at the confluence is minimal in size and depth and does not protrude into the channel, and because there is not a significant amount of fine sediment deposited on the bar below the confluence.

A bed material sample was collected of the sediment deposited at the head of the riffled flow split below the tributary confluence. The bed material consists primarily of coarse sand to sub-angular to well rounded coarse gravel with a D50 of 4.5 mm (fine gravel).

At about the middle of the reach there is a concrete grouted rock spillway on the right bank that drains a small detention basin. The detention basin appears to be used as a catchment for stormwater runoff from the parking area of a automobile dealership immediately to the south. The spillway contains a 6” PVC pipe that drains the detention basin onto a concreted grouted rock riprap overflow spillway (**Figure 9**). As seen in Figure 9, both the lower portion of the spillway is failing and the high, steep bank immediately to the east is slumping as a result of either the long-term degradation of the channel and/or toe scour along the bank at that location.

Figure 9. View of failing concrete grouted rock spillway and bank.

Just downstream from the spillway on the left bank is an old abandoned trailer park. Where the channel swings into the left bank at that location, large pieces of concrete and concrete rubble were placed along the bank, probably as bank protection for the park.

Directly across from the trailer park on the right bank are a number of buildings along the top of the bank. A small 1-inch diameter drain pipe with flowing water sticks out of the bank at this location. In addition, significant bank slumping (**Figure 10**) is occurring all along the site, probably as a result of both saturation of the bank from shallow ground water, seepage around the drain pipe, and toe scour or degradation along the bank. In addition, there are a number of tree stumps on the banks, inset floodplain, and in the channel in this area. The root masses of the stumps in the channel are providing some temporary grade control as indicated by the small drop in elevation from upstream to downstream at these locations.

Figure 10. View of slumping right bank 400 feet upstream of Westland Road bridge.

From the trailer park area downstream to the bridge the floodway is wider and there appears to be a high terrace and a lower, inset floodplain inset within the floodway. The higher terrace is about 4 feet above the channel bed and is somewhat hummocky (i.e., bumpy), whereas the inset channel banks (inset floodplain surface) are about 1.5-2 feet high. In places, the lower banks are eroding or slumping due to undermining, especially where small cobble bars have developed in the channel and are forcing flow into the banks. The left floodway embankment is riprapped for about 250 feet upstream of the Westland Road bridge.

The Westland Road bridge is skewed to the floodway and channel, but the piers are generally aligned with the floodway (**Figure 11**). Both spill-through abutments of the bridge consist of rock riprap enclosed in chain fencing similar to that used for gabions. A gravel-cobble bar has developed under the bridge and consists of a loose mixture of silt, sand, gravel, and cobbles up to 3-4 inches in diameter with cobble lag (quasi-armor) on the surface (**Figure 12**). The inset channel becomes poorly confined at the bridge and is the reason for the bar deposition under the bridge.

Figure 11. View looking downstream showing the Westland Road bridge.

Figure 12. View of unarmored cobble bar under the Westland Road bridge.

Westland Road / W. 24th St. Bridge to Missile Drive Bridge

This floodway in this segment is wider with numerous trees and the inset channel is more sinuous. Channel width ranges from about 10-12 feet at the upstream end of this segment to more than 20 feet in the lower part of the segment. Channel depth is generally about 1.5 to 2 feet. The stream bottom is generally composed of sand and gravel and some cobbles. Minor bank erosion, primarily due to undercutting, is evident intermittently throughout the segment.

Figure 13 shows the channel and floodway immediately downstream of the Westland Road bridge.

Figure 13. View looking downstream from the Westland Road bridge. Note the man-made wetland on the left bank.

Also note the man-made wetland on the inset floodplain of the left bank in Figure 13. The wetland has a cobble-boulder inlet at the upstream end and the area between it and the channel is protected by an armored berm. This wetland is not functioning properly because is situated well above the channel and is disconnected from hyperheic flows between it, the shallow groundwater table, and the channel. The wetland is only viable when there is a high flow sufficient to fill the wetland, but the water level in the wetland probably drops fairly rapidly soon after flows in the floodway recede.

Missile Drive is highly skewed (~45°) to the channel, but the box culverts at the bridge are aligned with the channel. However, the upstream channel makes a series of sharp bends before intersecting the bridge. The channel and floodway are bound on the south side by a railroad embankment with a concrete wall and on the north side by roadway embankments. The bridge consists of 4 box culverts and a concrete apron in the upstream approach of the channel (**Figure 14**). A minor amount of sediment has been deposited on the floors of the box culverts and the channel bottom immediately upstream of the approach apron is at or just below the top of the apron.

Missile Drive Bridge to W. 19th Street Bridge

A concrete exit apron and sediment deposits are present in the channel on the downstream side of the Missile Drive culverts (**Figure 15**). The sediment deposits, which are not extensive, consist of sand and gravel. The channel bed downstream of the bridge consists of sand and gravel and some cobbles.

Figure 14. View looking south along the upstream face of the Missile Drive bridge.

Figure 15. View looking downstream along the downstream face of the Missile Drive bridge.

The channel in this segment is slightly sinuous, meandering within a fairly wide floodway. The channel is generally about 10 to 15 feet wide and about 1-2 feet deep. The geometry of the floodway consists of a transitional inset high floodplain and a set of lower, inner benches bounding the inset channel (**Figure 16**). At the upstream end, the upper floodplain is about 3 to 4 feet above the channel bed and the inner benches are about 1-2 feet high. Near the downstream end, the inset floodplain becomes significantly higher (~8+ feet) relative to the channel. It is unknown if the inner benches are erosional or depositional, but they are likely depositional. Also, the boundary between the inner benches and the upper floodplain is fairly straight suggesting that the boundary between them may have been the bankline of a constructed channel and that the benches were deposited as the inset constructed channel adjusted its geometry over time. The effect is that the inset floodplain appears to transition from a true floodplain at the upstream end into a higher surface that probably doesn't flood at the downstream end, and the inset benches along the channel at the upstream end transition into a wider inset floodplain at the downstream end as seen in **Figure 17**. A number of young trees are currently growing on the inset floodplain throughout this segment.

Figure 16. View upstream showing shallow inset channel, low inner benches, and higher inset floodplain. Note concrete batch plant wall behind trees on left bank floodplain.

A comparison of the 1994 and 2005 aerial photography indicates that the inset channel has widened since 1994. There are several cobble riffles throughout this segment. There is also an underground concrete encased cable crossing about 300 feet upstream of the 19th Street bridge and intermittent concrete rubble and riprap in the channel for about 125 feet upstream of the 19th Street bridge. Some of the riprap may be associated with protecting the USGS gage located 40 feet upstream of the bridge on the right bank (see Figure 17).

Figure 17. View looking upstream from the 19th Street bridge showing high ground bounding an inset floodplain and channel. Note the USGS gage on the right bank.

In addition, just to the north of the channel on the left bank is a sand-gravel (S&G) supply yard and concrete batch plant(?). The plant appears to be encroaching on the floodway and, therefore, has constructed a concrete block wall to separate the channel and flood flows from the plant area (**Figure 18**). A small, intermittent tributary intersects the creek channel on the left bank at the upstream end of the wall which is located about 225 feet downstream of the Missile Drive bridge. The downstream end of the wall ends about 250 feet upstream of the 19th Street bridge and concrete rubble has been dumped intermittently on the left bank between the end of the wall and the bridge where the channel is impinging on the bank close to the plants access road.

Figure 18. View looking downstream showing the left bank concrete batch plant wall and the tributary confluence at the upstream end.

The 19th Street bridge consists of a series of 5 arched 6'x10' CMP culverts (**Figure 19**). Although the roadway is skewed to the channel and floodway, the culverts are aligned with the channel, but are skewed about 10-15° to flood flows. The inset channel flows though only one of the culverts whereas flood flows pass through all the culverts. Three of the 5 barrels are partially blocked with sediment possibly resulting in upstream backwatering and minor sedimentation during flood flows.

Figure 19. View from right bank looking downstream at the upstream face of the 19th Street bridge culverts and upstream floodway.

W. 19th Street Bridge to W. Lincolnway Bridge

This segment consists of a narrow, confined floodway that is bound by Martin Luther King Park on both sides (**Figure 20**). A pedestrian bridge crosses the channel about 425 feet downstream of the 19th Street bridge. Portions of the park infrastructure encroach into the floodway and into the channel just downstream of the pedestrian bridge (**Figure 21**). The channel along this segment is about 10 to 15 feet wide and is somewhat steep as indicated by the extensive number of riffles throughout the segment. Minor, intermittent bank erosion is present.

The channel exits the 19th Street bridge culverts along the right side of the floodway and meanders within an inset floodplain that is composed of in situ ancient alluvium that was excavated to create the floodway. The opening of the farthest right culvert at the 19th Street bridge is mostly blocked by a large tree growing in the barrel mouth. As indicated, the floodplain is composed of ancient alluvium consisting of well rounded material ranging from silt and sand to cobbles and small boulders. In most places, this floodplain material is generally cohesive. Recent overbank flows have deposited some small stringers of sand and gravel on top of the floodplain and in other places has scoured shallow depressions on the floodplain surface. The inset floodplain is densely vegetated with grasses, willows shrubs, and small trees along most of the segment.

The right embankment of the floodway contains a gabion bench along its toe for much of the length of this segment (**Figure 22**). This gabion bench appears to have been emplaced to protect the toe of the floodway embankment from scour and erosion. The gabion bench also extends for a short distance out onto the inset floodplain.

Figure 20. View looking upstream from the pedestrian bridge in Martin Luther King Park.

Figure 21. View looking downstream from the pedestrian bridge in Martin Luther King Park.

Figure 22. View looking upstream at gabion bench along the toe of the right floodway embankment.

Stormwater outfalls draining to the floodway are present on the left bank 55 feet upstream of the pedestrian bridge and on the right bank 315 feet and 70 feet upstream of the W. Lincolnway bridge. All three drains do not appear to be contributing a significant amount of sediment to the channel. However, the downstream most drain is currently being undermined because it is perched well above the channel and is creating a scour hole below its invert (**Figure 23**). The material scoured from below the drain as well as material being eroded from the stream bank at the drain outlet is contributing a minor amount of sediment to the creek.

Just upstream of the W. Lincolnway Bridge, the inset floodplain narrows significantly and at the bridge it disappears with the channel expanding to the entire width of the floodway. Because of the wider channel, sediments have deposited in bars just upstream and under the bridge (**Figure 24**). The sediment in the bars consists of silt and sand to pebbles up to 1.5 inches in diameter (**Figure 25**). The gravel and pebbles range from sub-angular to well-rounded. This type of material is also found in the channel bed throughout this segment, but the volume of material doesn't appear to be sufficient to cause long-term channel aggradation.

A bed material sample was collected from the channel about 100 feet upstream of the pedestrian bridge. The bed material consists of coarse sand to medium gravel with a D50 of 3.85 mm (very fine gravel).

As with the other segments, a comparison of the 1994 and 2005 aerial photography suggests that the channel in this segment has incised and widened, indicating that this segment is not broadly aggradational.

Figure 23. View of an undermined stormwater outfall on the right bank 70 feet upstream of the W. Lincolnway bridge.

Figure 24. View looking downstream at the W. Lincolnway bridge.

Figure 25. View of fairly well rounded gravel on bar just upstream of the W. Lincolnway bridge.

W. Lincolnway Bridge to Ames Avenue Bridge

This segment consists of a narrow, confined floodway with two sharp 90° turns between the W. Lincolnway bridge and a railroad bridge just downstream of the Capitol Basin outfall, followed by a straight, confined portion of channel that extends from the upstream railroad bridge, passes under another railroad bridge 485 feet further downstream, and then makes another 90° turn into the Ames Avenue bridge. The Capitol Basin outfall is located about 700 feet downstream of the W. Lincolnway bridge.

Below the W. Lincolnway bridge, flow reconsolidates into a defined inset channel ranging from 10 to 15 feet wide and less than 2 feet deep. The channel is bound by a low, well vegetated, inset floodplain. At about 400 feet downstream, the channel shallows significantly and flows become less confined and spread out over the inset floodplain (**Figure 26**) as a result of the decreased channel slope and backwater caused by the constriction of the floodway at the railroad bridge and embankment located just below the Capitol Basin outfall. The backwater cased by this constriction has resulted in deposition of sediment in the channel and in the overbank areas upstream of the railroad bridge.

Although the width of the opening at the railroad bridge is comparable to the upstream floodway width, the presence of the elevated Ames Avenue roadway along the channel has resulted in a significant decrease in the capacity of the bridge opening (**Figure 27**). In addition, the channel and floodway remained severely constricted by the high right bank and the elevated Ames Avenue roadway all the way to the Ames Avenue bridge (**Figure 28**). Therefore, the effective width for most flows through this segment is decrease by nearly half and, combined with a significant slope reduction along this segment, results in backwatering and significant

aggradation of the segment as seen in Figure 28. In addition, the Ames Avenue roadway is frequently overtopped by flood flows.

Figure 26. View south toward the railroad embankment 400 feet downstream of the W. Lincolnway bridge showing relatively unconfined flow along the creek.

Figure 27. View looking downstream showing the 2 railroad bridges and the elevated Ames Avenue roadway constricting the channel and floodway.

Figure 28. View looking downstream showing the downstream railroad bridge, the elevated Ames Avenue roadway, and the high right bank constricting the channel and floodway. Note the aggraded appearance of the channel due to extensive deposition of sand and gravel.

Downstream of the lower railroad bridge the channel remains severley confined between the elevated Ames Avenue roadway on the left bank and a gabion wall on the right bank. The creek makes a 90° bend at the Ames Avenue bridge crossing with the confluence pipe outfall of Dry Creek located along the right bank in the bend. The sharp turn in the channel and resultant backwater from the Ames Avenue bridge, the flat slope and constriction of the upstream channel and floodway, and the input of flow and the minor amount of sediment from Dry Creek all combine to create significant deposition and aggradation on the upstream side of the Ames Avenue bridge (**Figure 29**).

The Capitol Basin outfall is situated on the left bank about 100 feet upstream of the upper railroad bridge crossing (**Figure 30**). The outfall consists of 3 arched stone culverts that pass under Ames Avenue. A stone wall that separates the main creek channel from the outfall channel has been undermined by the channel and a scour hole that as developed immediately below the inverts of the culverts. The wall has broken in half and is failing. Grouted rock riprap that is present on the upstream side of the scour hole is broken and some of the stones have been displaced into the scour hole. **Figure 31** shows the configuration of the channel, separator wall, and scour hole at the outfall.

The Ames Avenue bridge consists of 8 sloped culverts that are 10 feet square. Thus, the channel and floodway width goes from 50 feet upstream of the bridge to 80 feet at the bridge opening. In addition, the roadway just north of the culverts overtops during flood flows, so this also increases the capacity of the bridge site to pass flows downstream. Although the bridge opening and roadway overtopping provides more flow capacity, the increased capacity at a given flow likely results in a decrease in flow depth and velocity and, thus, a decrease in sediment transport capacity through the bridge culverts. Nevertheless, there is still some

sediment that gets deposited in the channel downstream of the bridges as a result of passage of sediment from upstream of the bridge.

Figure 29. View looking upstream from the right bank at the Ames Avenue bridge crossing. The Dry Creek outfall is located in the bend of the gabion wall to the left of the picture.

Figure 30. View of the Capitol Basin outfall culverts and scour hole at Ames Avenue.

Figure 31. View looking upstream showing the creek, the separator wall, and the scour hole at the Capitol Basin outfall.

Just downstream of the Ames Avenue bridge, the channel is very wide and shallow. The sediment that has been deposited in the channel immediately below the bridge is much finer grained with less gravel and no cobbles, unlike that deposited upstream of the bridge.

Ames Avenue Bridge to W. 9th Street Bridge

This segment extends from the Ames Avenue bridge to the east and then turns to the southwest before intersecting the W. 9th Street bridge. As seen in Figure 5b, this segment represents the relocated channel section of the creek that was moved from its position about 1,400 feet to the south (and aligned with W. 7th Street) after 1870 to its current location by 1911. As a result, the inset floodplain is in situ ancient alluvium exposed during excavation of the floodway. The inset channel may have been constructed, but it is more likely that the current inset channel is a product of the development of low flow confinement and long-term degradation within the constructed floodway.

The floodway top width throughout this segment averages about 100 feet, which is generally the same as or slightly less than the floodway top widths in the segments upstream. The floodway embankments are mostly unvegetated and, where the channel impinges on or come close to them, are intermittently armored with rock riprap. A silt fence is present along the entire length of the right embankment toe in this segment. **Figure 32** shows the middle part of the segment, which is typical of the channel and floodway morphology in this segment. A number of small stormwater outfalls are located on both floodway embankments, but most are situated along the south (right) floodway embankment to drain the low areas and roadways immediately to the south. There was no significant amount of sediment deposited within the barrels of the outfalls or on the spillways below the outfalls. This may indicate that there is little roadway sediment transported to the creek in this area.

Figure 32. View looking upstream from the middle of the Ames Avenue bridge to W. 9th Street bridge segment of Crow Creek.

The inset channel in this segment is typically about 15 to 20 feet wide and about 2 feet deep at riffles to 4 feet deep at runs and pools. In a few places, the streambank can be more than 5 feet high. The streambanks are vertical and raw in a few spots, but where bank erosion is apparent, bank retreat is slow. The streambanks are generally cohesive and can include material ranging from silt to cobbles and small boulders (**Figure 33**). In places, the inset floodplain has small stringers of sand and gravel deposited on it and in other places small depressions have been scoured into the surface of the floodplain.

From the Ames Avenue bridge to the rock weir located about 570 feet downstream, the inset channel is flat and wide flowing within a low inset floodplain. Because of the flat slope, which is created in part by the downstream rock weir, fine grained sediments have been deposited in the channel in this part of segment.

The inset channel below the rock weir in this segment becomes steeper, deeper, and narrower with much coarser bed material. A bed material sample was collected at a riffle just downstream of the RESPEC stream gage, which is located near the intersection of Deming Drive and O'Neil Avenue. Although there is a lag of very coarse gravel and cobbles on the surface of the channel bed, the underlying bed material ranges from coarse sand to very coarse gravel with a D50 of 19 mm (coarse gravel). The cobbles in the channel bed (**Figure 34**) appear to have been eroded locally from the channel banks and bed during long-term channel degradation and widening that has occurred in this segment. The cobbles are loosely deposited on the bed and, therefore, are likely transported, at least for short distances, during only the largest flood events. The gravel to cobble sized material creates an intermittent armor on the bed of the channel throughout this segment and especially in the riffles.

Figure 33. View of eroding left bank just downstream of the RESPEC gage near the intersection of Deming Drive and O'Neil Avenue.

Figure 34. View of sand to cobble bed material in channel downstream of the RESPEC gage near the intersection of Deming Drive and O'Neil Avenue.

There are several cobble riffles of varying lengths in the segment. Several short riffles occur in the channel for several hundred feet downstream of the rock weir. The first major cobble riffle is located just north of the intersection of Deming Drive and Bent Avenue and is about 145 ft long. The next major riffle is located just north of the intersection of Deming Drive and O'Neil Avenue and is about 190 ft long. A third major riffle is located in the bend of the floodway and is about 125 ft long.

A concrete encased pipeline crossing is located in the channel about 310 feet upstream of the 9th Street bridge (**Figure 35**). The pipeline crossing is fully exposed and creates a 2 ft drop in the channel from the upstream side to the downstream side. The downstream side of the concrete encasement may have been undermined in the past, but is currently protected with rock riprap.

Figure 35. View toward the left bank showing the concrete encased pipeline crossing and 2 foot drop upstream of the 9th Street bridge.

The W. 9th Street bridge is a 3 span bridge with 2 sets of pier within the channel and gabion paved spill-through abutments. Since there is no vegetation under the bridge, the inset channel spreads out to the full width of the bottom of the floodway under the bridge. Although the floodway top width upstream of the bridge is about 100 feet, it narrows to about 80 feet at the bridge. There is some evidence of streambed scour under the bridge.

<u>W. 9th Street Bridge to W. 5th Street Bridge</u>

This segment consists of a straight man-made floodway that is slightly narrower (<90 ft) at the top and a slightly meandering inset channel bound by an inset floodplain. The inset channel width varies, with some sections up to 30 feet wide and other sections less than 15 feet wide.

The inset channel depth relative to the inset floodplain is about 2 to 3 feet. A pedestrian bridge crosses the floodway at about the middle of the segment where the downstream end of the old 1870 channel would have intersected the current channel.

The channel and floodway morphology of this segment, as shown in **Figure 36**, is similar to the segment upstream of the 9th Street bridge in that there are a number of small riffles along the channel, the floodplain sediments are composed of exposed ancient alluvium, the channel bed sediments range from sand to cobbles, and there is intermittent erosion of both the banks of the inset channel and the floodway embankment. The entire length of the left floodway embankment is revetted with what appears to be hand placed stone. Similar stone revetment is evident intermittently on the right floodway embankment. Where the stream impinges on the embankment, the stone is failing and slumping into the channel (**Figure 37**). Some of this stone has formed riffles in the channel in places. Some of the riffles not associated with bank erosion are also composed of riprap stones, although it is unclear where the stones came from or how they ended up in the riffle.

Figure 36. View from pedestrian bridge looking upstream toward the 9th Street bridge showing the inset channel and floodplain within the relatively narrow floodway of Crow Creek.

The stormwater outfalls that are present along the right floodway embankment contain little or no sediment within their barrels or at the outfall. In several places the ground under the outfall is paved with interlocking open blocks (**Figure 38**). Although the openings in the blocks are partially filled with sediment, there is little excess sediment on the blocks which may be an indication that the stormwater drains are contributing little sediment to the creek. These outfalls will have a tailwater condition as flow rises above the inset channel.

Figure 37. View of eroding left floodway embankment showing failing stone revetment.

Figure 38. View of stormwater outfall along the toe of the right floodway embankment just downstream of the 9th Street bridge.

Beginning about 200 feet upstream of the 5th Street bridge, there are interlocking blocks paving the right floodway embankment for about 80 feet downstream. These blocks appear to have been emplaced recently, possibly due to severe erosion or slumping of the embankment. At about the same location on the left side of the floodway, the paved pedestrian trail splits with one part of the trail dropping down to the inset floodplain and passing under the 5th Street bridge

(**Figure 39**). The pedestrian trail under the bridge doesn't appear to significantly reduce the floodway's capacity under the bridge since it is at about the same elevation as the inset floodplain. However, where the trail slopes upward to the top of the embankment, the fill slope for the trail does create a slight constriction of the floodway. Rock riprap is present along the toe of the trail wall to protect it from scour. The trail wall also confines the inset channel to the middle of the floodway and restricts the eastward migration of the channel.

Figure 39. View looking upstream toward the W. 5th Street bridge, the inset channel, and the pedestrian trail under the bridge. The bridge width is also the floodway width.

The W. 5th Street bridge is a double span bridge with a single pier situated in the channel. The bridge abutments are spill-through abutments with gabion paving. There is no floodplain or bar development under the bridge since the slope of the channel through the bridge section is fairly steep. Both abutments are vertical walls with fill material placed along the toe of the wall. The fill material includes large round cobbles and small boulders. Rounded cobbles and small boulders in the channel bed are creating riffled flow under the bridge.

Bar and bed material below the bridge ranges in size from coarse sand to very coarse gravel. The gravel is well rounded indicating that it is derived from an alluvial source. The bars are partially armored with pebbles to 1-1.5 inches in diameter (**Figure 40**).

W. 5th Street Bridge to Central Avenue / I-180 Bridges

This segment consists of a floodway with a top width of about 100 feet, an inset floodplain, and an inset channel. The inset channel is about 3 to 4 feet deep within the inset floodplain. Channel width ranges from 8 feet to 20 feet, but averages about 12 to 15 feet in width. The inset floodplain is densely vegetated with grasses and reeds. Highwater debris is present along the top of the inset floodplain at about 2 to 3 feet above the top of the banks. The floodway makes a major bend to the east immediately downstream of the 5th Street bridge. A pedestrian bridge crosses the floodway at about 615 feet downstream of the 5th Street bridge. The Central Avenue bridge is located about 670 feet further downstream.

Figure 40. View of sand and gravel bar just downstream of the 5th Street bridge.

Large boulders have been placed along the left bank just downstream of the 5th Street bridge beginning at a point where the pedestrian path slopes back up to the top the left floodway embankment. This revetment extends for about 100 feet downstream.

A small stormwater outfall and paving block spillway as well as a large stormwater outfall with a grouted riprap spillway are present on the right floodway embankment about 350 feet downstream of the 5th Street bridge. This larger outfall and grouted rock spillway appear to have been emplaced after 2006 based on an examination of the aerial photos for the area. In addition, erosion of the upper embankment slope just downstream of these outfalls suggest that recent flood flows within the bend of the floodway may have caused some toe and slope erosion of the right embankment within the bend. Surface runoff from the south is causing slopewash erosion at the top of the right floodway embankment as well (**Figure 41**).

The pedestrian bridge located 615 feet downstream of the 5th Street bridge crosses the floodway at a skew. The upstream and downstream banks and both wall abutments of the bridge are protected by rock filled gabions slope protection. **Figure 42** show the inset channel and floodplain of the floodway just upstream of the pedestrian bridge.

Immediately downstream of the pedestrian bridge, the inset channel makes a sharp “S” turn from the left side to the right side of the floodway. The sharp turn is likely related to the dense root structures of several mature trees along the left side of the floodway. There is also a young tree growing in the middle of the floodway. The root structures from these trees are likely providing significant cohesion to the left bank of the channel and the inset floodplain on the left side of the floodway. This is forcing the inset channel and flows to migrate toward the right floodway embankment. As a result, the right embankment toe is being undermined, which has created a massive 85 foot long slump in the embankment as shown in **Figure 43**.

Figure 41. View of erosion at the top of the right floodway embankment about 400 feet downstream of the 5th Street bridge.

Figure 42. View looking upstream from the pedestrian bridge located 615 feet downstream of the 5th Street bridge.

Figure 43. View looking downstream from the pedestrian bridge located about 615 feet downstream of the 5th Street bridge. Note the large slump on the right bank.

The material being contributed to the channel from the upper bank of the slump contains colluvial sediments likely derived from nearby sandstone-like outcrops. The sandstone-like outcrops, which appear to be part of a Pleistocene terrace deposit, consist of slightly to moderately lithified sand to well rounded, cobble and small boulder sized alluvium. The upper bank sediments are somewhat cohesive as indicated by the vertical face. The lower, non-cohesive bank material consists of older, well rounded, alluvial silt to cobble sized sediments, whereas the bank toe consists of a very cohesive dark gray, clayey, silty, sand, which may be representative of an old soil horizon, underlain by non-cohesive sandy gravel alluvium. **Figure 44** shows the typical material being contributed to the channel by the right bank slump.

There are other areas of bank erosion and slumping between the pedestrian bridge and the Central Avenue bridge (**Figure 45**). Most of these slumps occur along the banks of the inset channel, are still root bound, and, therefore, do not provide much sediment to the channel. Most of this slumped material is fine grained, organic rich, floodplain soils. However, the bed material of the channel in this area consists of sands and gravels and some cobbles.

Near the Central Avenue bridge, the channel begins to deepen and impinge on the right side of the floodway. About 60 feet upstream of the bridge is a surface runoff blacktopped sloping spillway on the right floodway embankment that has created a major scour hole below itself. This scour hole has resulted in a partial failure of the lower spillway slope and undercutting of the embankment.

Of particular note is the poor alignment of the inset channel with the Central Avenue bridge culverts (**Figure 46**). It is unknown if this alignment was intentional or if long-term channel migration to the south created this condition. Regardless, the channel has migrated well into the right bank causing undermining of about 100 feet of the right bank (**Figure 47**), the paved surface runoff spillway, and the wingwall at the south end of the bridge.

Figure 44. View of sediments and toe material at the right bank slump just downstream of the pedestrian bridge located about 615 feet downstream of the 5th Street bridge.

Figure 45. View looking upstream showing slumping right bank upstream of Central Avenue.

Figure 46. View looking downstream at the Central Avenue bridge culverts.

Figure 47. View of failing right bank just upstream of the Central Avenue bridge. Note the similarity of the bank material to that in the slumped bank upstream of the pedestrian bridge.

The Central Avenue bridge consists of five 12-foot square box culverts, only one of which is aligned with the inset channel. The other culverts have filled with sediment up to or just below the same elevation as the inset floodplain at the upstream end. The sediment in the culverts ranges from sand to very coarse gravel and small cobbles up to 3 inches in diameter (**Figure 48**).

Figure 48. View of sand, gravel, and small cobbles in one of the Central Avenue box culverts.

The box culverts at Central Avenue extend for about 300 feet under the I-180 embankment making a turn of about 15° to the south at about the halfway point. The bottoms of the culverts that aren't occupied by channel flow are covered with sand and gravel over their entire length (**Figure 49**). Only the farthest south culvert contains flow from the inset channel. The other culverts only carry flow at flows equal to or greater than Bankfull.

Figure 49. View looking downstream along the middle box culvert under I-180. Note the sand and gravel deposits in the bottom and the 15° turn to the right (south) of the culvert.

I-180 Bridge to E. 1st Street / Deming Drive Bridge

This segment consists of a narrow (~100 foot top width), confined floodway from the I-180 culverts to a point about 550 feet downstream. At that point the floodway widens significantly and makes a turn to the south before intersecting the 1st Street bridge. At the bend in the floodway, the top width of the floodway is about 230 feet at its widest point. A concrete wall (floodwall?) about 3-4 feet high extends along the top of the right embankment for the entire length of this segment.

Warren Avenue crosses the floodway about 90 feet downstream of the I-180 culverts. The inset channel within the short span is fairly shallow, with the bed material consisting primarily of sand and some gravel. The inset floodplain is fairly low relative to the channel. Three roadside drainage outfalls are located on the banks – two are swaled concrete surface drainage channels and the other is a subsurface stormwater pipe. The surface drainage channel on the right floodway embankment drains from large parking lots to the south as well as the southeast I-180 road embankment. As a result, the drain is partially buried in sand and gravel that has runoff from these areas (**Figure 50**). Riprap has been placed in the creek bottom where the subsurface stormwater drain empties into the creek on the left bank.

Figure 50. View to the south showing the partially buried concrete surface drainage channel that empties into the creek on the right bank between Warren Avenue and I-180.

The inset channel between the Warren Avenue bridge, which was replaced in the summer of 2008, and the point where the floodway widens becomes deeper in the downstream direction (**Figure 51**). The bed of the channel in this reach is somewhat steeper, and thus the bed material is much coarser. At the point where the floodway widens, the channel shallows quickly and flow is allowed to spread out within the bottom of the floodway. The bottom of the floodway at this location does not have a true inset floodplain, but instead has an irregular topography of high bars and intervening swales that is inundated at moderate to high flows. With the wide bend of the floodway, the bed and bar materials range from sand to very coarse gravel and some small cobbles, with some armoring of both the bed and bars.

Figure 51. View looking downstream from the Warren Avenue bridge showing the downstream floodway and inset channel.

Significant changes have occurred within the widened floodway area between 1994 and 2005, based on an examination of the aerial photos from those years. The floodwall on the left bank was not present, the channel was much narrower, and the channel was present along the left bank in 1994. By 2005, the floodwall was constructed along the top of the left bank. More importantly, the 1st Street / Deming Avenue crossing, which consisted of a series of 5 arched culverts in 1994, was replaced by the current 4 span, concrete bridge by 2005. In addition, the inset channel had been artificially re-routed along the right bank side of the floodway and is much wider than the 1994 channel.

The arched pipe culverts at the 1st Street crossing likely contributed to the wider floodway upstream because of backwater sedimentation that they induced. Following their replacement and the channel realignment, the channel was able to adjust resulting in entrenchment to its current elevation and a partial abandonment of the inset floodplain. The greater capacity of the new bridge would also have allowed degradation and flushing of finer sediments from the upstream inset floodplain into the reach downstream of the bridge. **Figure 52** shows the inset floodplain and inset channel relative to the floodway and the 1st Street bridge and **Figure 53**

shows the exposed sand and gravel on the surface of the low inset floodplain relative to the shallow inset channel. Because of the lack of vegetation under the bridge, there is also a significant amount of exposed sand and gravel under the bridge.

Figure 52. View looking downstream toward the 5-span 1st Street bridge showing the floodway, low inset floodplain, and shallow inset channel.

Figure 53. View toward the east showing exposed coarse sand and gravel along the edge of the low inset floodplain seen in Figure 52.

A bed material sediment sample was collected from the channel about 145 feet upstream of the 1st Street bridge. As with the other bed samples, any surface armor that was present was

removed prior to collecting the sample. The bed material consists of unconsolidated coarse sand to coarse gravel with a median grain size (D50) of 9.5 mm (medium gravel). Most of the gravel is sub-angular to well-rounded.

Along with the new bridge, gabion bank paving had been placed along both floodway embankments by 2005. The left embankment gabion slope protection extends about 340 feet upstream while the right embankment gabion slope protection extends about 120 feet upstream. A concrete pedestrian trail and protective wall passes under the bridge on the left side of the floodway, but creates very little constriction in the floodway.

E. 1st Street / Deming Drive Bridge to Morrie Avenue Bridge

This segment is about 2,500 feet long and consists of a floodway with a variable width, an inset channel that varies in width and depth, but is generally about 12 to 15 feet wide and 2-3 feet deep, and an inset floodplain. The floodway makes a broad turn, flowing to the southeast below the 1st Street bridge and then turning back to the northeast about 900 feet downstream. A number of small cobble riffles, some of which have a fairly steep drop, are present throughout the segment. The floodplain in this segment is densely vegetated with mature cottonwood and willow trees, bushes, and grasses.

The creek and floodway impinge on a bedrock (sandstone) hillslope on the right bank at about the middle of the bend, which is the narrowest point of the floodway. Interstate 80 runs along the top of the hillslope. Shallow slumping, surface creep, and overland erosion of the hillslope soils as well as road sediment runoff from I-80 are contributing a minor amount of material to the sediment load of the creek at this location. Where the creek impinges on the toe of the hillslope, erosion of the right bank is slowly occurring. **Figure 54** shows all these features.

Figure 54. View looking downstream showing eroding bedrock hillslope and right bank of channel just downstream of the 1st Street bridge.

At about 900 feet downstream of the 1st Street bridge, the floodway widens and becomes densely vegetated. A subsurface sample of the floodplain sediments was collected on the left bank side at this location. The top 8 to 10 inches consisted of organic silty, sandy soil that was heavily root bound. Below this organic rich soil is unconsolidated coarse sand to medium gravel that is well rounded. The median grain size (D50) of the material is 3.9 mm (fine gravel). The water table, which was at about the same elevation as flow in the channel, was reached at a depth of about 2 feet. A wide range of material, from silt and sand to well-rounded very coarse gravel and small cobbles, is evident in the banks and in the floodplain throughout this segment.

At about 200 feet downstream from the floodplain sample site, the inset channel shifts to the left side of the floodway and flows in a fairly straight path along the left floodway embankment for almost the entire remainder of this segment. Because the channel is impinging directly on the left embankment, which was likely causing erosion and failure of the bank, the bank was recently revetted with rock riprap at four sites ranging in length from 90 feet to 130 feet. The first riprap site is located about 1,150 feet downstream of the 1st Street bridge. The other three sites, which are in close proximity to each other, are located between 480 and 950 feet upstream of the Morrie Avenue bridge.

The downstream three revetted sites also correspond with an old flow diversion and split flow channel on the right side of the floodplain. The structure, which is visible in the 1994 aerial photos, was located about 950 feet upstream of the Morrie Avenue bridge. Although the structure is no longer present, a large riffle is present at the upstream end of the flow split. The split flow channel appears to carry flow only during bankfull and greater flows. The downstream end of the split flow channel reconnects with the creek channel at about 400 feet upstream of the Morrie Avenue bridge.

The main creek channel in the split flow channel portion of this segment also appears to have been significantly modified. The inset channel is narrow, steep, deep, and very straight indicative of a man-made channel. The right bank in this reach is also fairly high (5+ feet) relative to other locations. **Figure 55** shows the straight channelized reach of the creek at this location. At the downstream end of the reach at about 530 feet upstream of the Morrie Avenue bridge, riprap has been placed across the bed of the channel and along the right bank for a short distance upstream. Immediately downstream of the riprap is a large scour hole which has cut into the right bank forming a “blowout.” This riprap appears to be providing grade control since there is an overall drop in bed elevation from upstream to downstream of about 1-2 feet. Given the appearance of the “blowout” and the riprap in the channel bed, the riprap may have been emplaced to capture a knickpoint in the channel at that location.

Downstream of the channelized reach, the creek returns to a wider, shallower, somewhat meandering channel. The downstream end of the split flow channel intersects the main channel there as well.

At about 275 feet upstream of the Morrie Avenue bridge on the left bank is the recently constructed Morrie Avenue stormwater outfall. The outfall consists of a concrete structure protected by rock riprap around its margins. There is also a rock riprap channel that connects the structure with the creek channel and rock riprap has been placed across the channel and on the right bank of the creek across from the outfall. **Figure 56** shows pictures taken in March and June showing the configuration of the outfall in relation to the creek channel. The March photo shows some minor sediment deposition within the rock riprap, whereas the June photo shows a minor sand and gravel bar on the downstream side of the riprap channel near the headwall. The March sedimentation appears to be due to contributions from the stormwater

outfall whereas the June sediment deposits may be related to both outfall sediments as well as to eddying of creek flow into the riprap with deposition of sediment transported by the creek.

Figure 55. View looking upstream at the long, channelized straight reach upstream of the Morrie Avenue bridge. Note the rock riprap in the channel at the bottom left corner of the photo.

From the outfall downstream to the Morrie Avenue bridge, the channel shallows and widens even more. At a point about 130 feet upstream of the bridge, the channel expands rapidly from 12-15 feet wide to about 120 feet wide at the bridge. A considerable amount of sand and gravel is present in the channel bed and in low bars upstream, under, and downstream of the bridge (**Figure 57**). The sand and gravel deposition at this location is likely an artifact of the previous bridge, which consisted of six 10-foot square box culverts which created significant upstream backwater sedimentation during flood flows. The old bridge was replaced with the current bridge, which consists of 2 spans, in 2007. As a result of the much wider channel, conveyance of flows has significantly increased, but because of the wider channel area, flow depths and velocities for a given flow are now likely lower, resulting in a somewhat reduced sediment transport capacity at the bridge. Thus, subsequent high flows have winnowed the finer material from the channel leaving behind a gravel armor layer which is best developed on the bars. **Figure 58** shows the gravel deposits and a gravel riffle in the channel just upstream of the bridge. **Figure 59** shows the gravel armor on a bar and the underlying sand to gravel sized material at this same site.

A bed material sample was collected from the bar shown in Figure 59. The surface armor was removed first and a sample was collected of the subsurface sediments. The bed material just upstream of the Morrie Avenue bridge consists of very fine sand to fine gravel with a median grain size (D50) of 1.2 mm (very coarse sand).

Figure 56. Comparison of March (top) and June (bottom), 2010 photos looking upstream at the recently constructed Morrie Avenue stormwater outfall on the left bank and the creek channel.

Figure 57. View looking downstream showing the new 2-span Morrie Avenue bridge.

Figure 58. View of gravel bars and riffle in the channel upstream of the Morrie Avenue bridge.

Figure 59. View of gravel armor on a bar just upstream of the Morrie Avenue bridge.

Morrie Avenue Bridge to Haystack Bridge (Refinery)

This segment of the creek represents the creek in a more natural state – that is, there is no constructed floodway downstream of the Morrie Avenue bridge and the creek is free to meander within its unconfined floodplain. A 2-span concrete bridge that connects the oil refinery to the north with a small storage tank facility to the south crosses the creek about 0.25 miles due east of the Morrie Avenue bridge. There are 2 diversion structures in the channel between the Morrie Avenue bridge and the refinery road bridge. Further downstream is the Haystack farm road bridge, which is located about 0.75 miles due east of the Morrie Avenue bridge.

The channel depth varies from 1 to 3 feet depending on location. Immediately below the Morrie Avenue bridge is the remnant of a split flow island that formed when the old bridge culverts were present. This island is currently being degraded and eroded as seen in **Figure 60**. Downstream of the island, the channel narrows to its normal width. From the Morrie Avenue bridge to the refinery road bridge the channel is about 20-25 feet wide, is about 2 to 4 feet deep, and has a sinuosity of about 1.13.

Figure 60. View looking downstream from the Morrie Avenue bridge. Note the remnants of the split flow island due to degradation and erosion following the replacement of the bridge.

The 2 diversion structures between the Morrie Avenue bridge and the refinery road bridge are located at 760 feet and 1,270 feet downstream of the Morrie Avenue bridge. The upstream structure diverts flow into a concrete lined irrigation channel on the left bank. It is unclear if this irrigation channel is still functional. The downstream diversion structure diverts flow into an excavated irrigation channel on the right bank producing a flow split with the channel widths of both the diverted irrigation channel and the main channel being about 12 to 15 feet. Part of the flow from the irrigation channel is diverted under the refinery road about 160 feet south of the intersection of the irrigation channel and the main channel upstream of the refinery road bridge.

A large blowout of the floodplain is present where the irrigation channel reconnects with the main channel upstream of the refinery road bridge. Overbank channels with headcuts extend upstream from the blowout where overbank flows return to the channel. An extensive amount of sand, gravel, and small cobbles have been deposited on the upstream side and under the bridge.

Downstream of the refinery road bridge, the channel deepens to about 4 or 5 feet, depending on location, and becomes more sinuous (1.21). The channel width goes from about 15 to 20 feet at the bridge to about 10 to 15 feet near the Haystack farm road bridge. The channel is generally equal width, with minor point bar development along the insides of sharp bends. A few old cutoffs are evident in the floodplain in this reach.

A bed material sample was collected from the upstream side of a small point bar in a bend located about 1,335 feet upstream of the Haystack farm road bridge. The unconsolidated bed material ranged from coarse sand to medium gravel with a median grain size (D50) of 4.9 mm (fine gravel). Throughout the segment, exposed or eroding banks were found to contain an upper, cohesive, floodplain soil horizon consisting if clayey, silty, sand, underlain by coarser, less cohesive, alluvial materials ranging from sand to gravel.

A comparison of the 1994 and 2005 aerial photos indicates that this segment has widened significantly. In addition, point bar development in this segment in 1994 was negligible compared to 2005 suggesting that the current channel has a greater capacity to transport sediment.

Sediment Sampling and Sample Analysis

Bed material and floodplain samples were collected on August 19, 2010. As described above, the bed samples were collected from the channel at 5 locations – (1) downstream of the I-25 bridges, (2) below the Ames Avenue bridge near the intersection of Deming Drive and O'Neil Avenue, (3) upstream of the W. 1st Street bridge, (4) just upstream of the Morrie Avenue bridge, and (5) upstream of the Haystack farm road bridge. There were 2 floodplain samples collected as well; one on the inset left bank floodplain upstream of the I-25 bridges and one on the left bank floodplain just downstream of the W. 1st Street bridge.

Figure 61 shows the grain size distribution for all the samples. There are 3 comparisons of particular note. The first is the comparison of the floodplain sediment sample upstream of I-25 with the bed sediment sample collected upstream of the Morrie Avenue bridge. Both these samples have similar grain size distributions and are finer grained than the other samples. This is likely due to the impacts of upstream backwater sedimentation associated with constrictions cased by old bridges at these locations.

The second comparison is of the bed samples collected downstream of the I-25 bridges, at MLK Jr. Park, and upstream of the Haystack farm road bridge with the floodplain sample collected just downstream of the W. 1st Street bridge. These samples also have similar grain size distributions, which suggest that the sediment that enters the upstream end of the project reach is no different than the sediment that is contributed to and passes through the middle of the reach and into the lower part of the reach. In addition, the sediment that is contributed to the creek is easily transported through the reach, given flows of sufficient magnitude and duration necessary to mobilize the sediment.

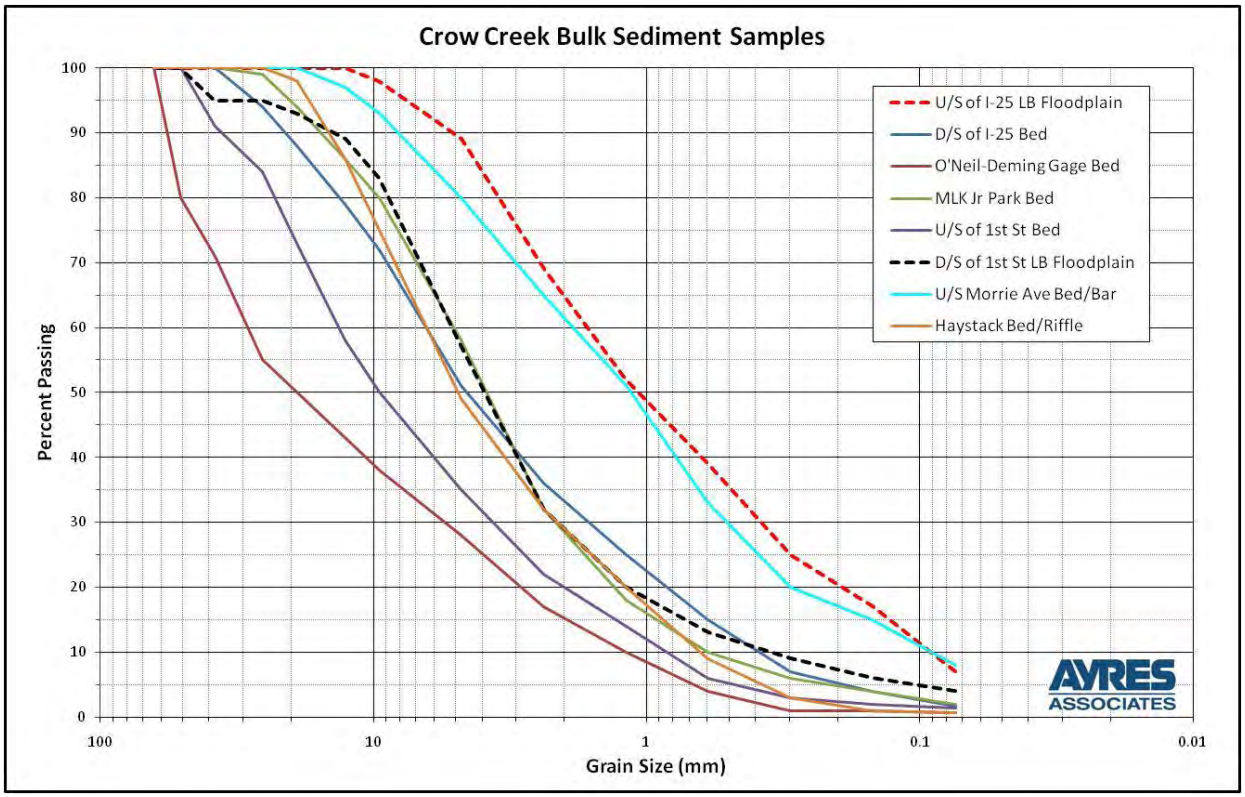

Figure 61. grain size distributions of bulk sediment samples collected from the bed and floodplain of Crow Creek.

The third comparison is of the bed samples collected near the O'Neil Avenue and Demng Drive intersection near the RESPEC stream gage and the bed sample collected upstream of the W. 1st Street bridge. Both these sites are representative of a channel that has been rerouted and artificially modified. The O'Neil – Demming site is within the section of creek that was moved from its natural location more than 1,400 to the south to its current location. The channel and floodplain are part of a floodway excavated at this location. The site upstream of the W. 1st Street bridge was part of the replacement of the bridge and rerouting of the channel from the east side of the floodway to the west side of the floodway upstream of the bridge. Subsequent winnowing of fines from the top of the floodplain and from the channel bed has created resulted in coarser material being left behind.

Conclusions

Based on the above analysis, it is readily apparent that the current channel is the product of extensive channel and floodway modification over the last 140 years and subsequent channel adjustments to those modifications. Those adjustments include channel degradation and widening and possible localized armoring of the channel bed.

Channel degradation, bank erosion and sediment from construction sites can be sediment sources. Although extensive road sanding occurred in the past, the City has indicated that it now only applies about 300 tons of sand and gravel to the roadway once after the first major storm, usually in January, and that much of what is applied is swept up immediately after the snow melts. Magnesium chloride is applied to the roadways in the City during all subsequent

storms. Given that the current channel width remains relatively constant and there is no significant development of bars within the channel, it is likely that the channel is either in a quasi-stable or slightly degradational condition with regard to sediment transport capacity. This is supported by the lack of significant deposition of sediment in the channel on the inset floodplain during and following recent high flows. An examination of the inset floodplain throughout the project reach following the high flows in June, 2010, revealed little sediment deposition on the inset floodplain and no significant deposits of sediment within the channel.

Another indicator of stability is the lack of major bank erosion or any significant migration of the inset channel. An examination of the historical aerial photography indicates that the inset channel within the floodway has generally remained in its current position since at least 1994. Finally, the fact that the channel has a fairly constant width throughout the project reach, both in straight reaches and in bends, is another indicator of stability. Brice (1975) showed that single phase and two phase equal width channels (Figure 61) are stable and fairly static over long periods, which was further verified by Lagasse et al. (2004).

Based on this geomorphic assessment, it can be concluded that Crow Creek is geomorphically stable and able to mobilize and transport the sediment that is currently supplied to it, given the appropriate flows. The volume of sediment contributed by the Capitol Basin and the Morrie Avenue stormwater outfalls is currently unknown, but future bedload sediment sampling efforts at the outfalls and along the creek may provide sufficient information to answer that question. A comparison of the Deming Drive, Morrie Avenue and Haystack sites with the sediment competence data from the WDEQ 2009 Crow Creek Assessment Report is currently underway.

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